



# Evaluating the effect of urbanization and foreign direct investment on water use efficiency in West Africa: application of the dynamic slacks-based model and the common correlated effects mean group estimator

Ethel Ansaah Addae<sup>1</sup> · Dongying Sun<sup>1</sup> · Olivier Joseph Abban<sup>2</sup>

Received: 12 April 2021 / Accepted: 10 March 2022 / Published online: 22 March 2022  
© The Author(s), under exclusive licence to Springer Nature B.V. 2022

## Abstract

This study examined the pattern of water use efficiency and its potential relationship with urbanization and foreign direct investment between 2007 and 2016 in 11 West African countries. According to the dynamic slacks-based model of data envelopment analysis, Benin, Burkina Faso, Liberia, Mauritania, and Togo met the efficiency frontier of 1.00 while the rest of the countries were below average (0.50). Also, since the total efficiency score (0.627) was less than the optimum efficiency frontier of 1.00, then economic growth, which was used as a carryover variable, had a negative impact on water use efficiency in West Africa as a whole. The cross-sectional independence tests were all meaningful at 1%, suggesting that the null hypothesis of cross-sectional independence in this analysis was rejected. This indicates that there are dependencies among the sampled countries, prompting the use of cross-sectional Im, Pesaran, and Shin unit root tests, as well as cross-sectional augmented Dickey–Fuller unit root tests, which were all initially non-stationary but became stationary after first difference. Furthermore, the common correlated effects mean group (CCEMG) panel estimator was employed to examine the long-run relationships that exist in the sampled series. From the results of the estimation, urbanization had a vital impact on water use efficiency (WUE) across all panels; foreign direct investment had a significant positive influence on WUE in the main and lower-middle-income (LMI) panels but insignificant in the low-income (LI) panel. In addition, export had a significant impact on WUE in the LMI panel but had an insignificant impact on the main and LI panels. Also, industrial activities had a significant negative effect on WUE across all panels, and finally, literacy rate had a positive influence on WUE in the LMI panel but offered an insignificant effect in the main and LI panels. The dynamic common correlated estimated mean group estimation finding, which was used for robustness tests, confirmed the CCEMG estimation result. Policy recommendations based on the results are further discussed.

**Keywords** Dynamic slack-based model-DEA · Water use efficiency · FDI · Urbanization · CCEMG

---

✉ Ethel Ansaah Addae  
x25ethel@yahoo.com

Extended author information available on the last page of the article

## 1 Introduction

Water is an important and strategic economic and natural resource. It forms the basis of survival and development in both ecological and human society. However, the world now faces a severe water resources crisis because of water shortages and pollution. This shortage has also become a critical issue that restricts economic development. According to Wang et al. (2018), approximately 1.8 billion people will face an absolute water shortage by 2025, and nearly two-thirds of the global population may live under water tension. From a resource distribution of countries in West Africa, rainfall has increasingly fluctuated due to climate change, whereas precipitation in the northern part of most of these countries has decreased in recent years (Nicholson et al., 2018). This unbalanced distribution of water resources has created problems due to its unreasonable structure and total water supply insufficiencies (Yeleliere et al., 2018). In addition, the repercussion of water and environmental pollution such as water-related diseases, inadequate food production, an insufficient supply of quality water, poverty, waste from the mines and other industries, leaching, flooding, and drought are some of the problems affecting both humans and the ecosystem (Baloch et al., 2021; Fayiga et al., 2018; Rustam et al., 2020). For instance, Akpan and Olukanni (2020) have reported that the total waste discharged in Cote D'Ivoire, Ghana, and Nigeria was 335,000, 419,000, and 2,469,000 ton/yr, respectively. For these reasons, efficient use of water resources cannot be relegated when considering ways and means of tackling the crisis of water stress in West Africa.

At present, researches on water use efficiency have mainly focused on the estimation of total water use efficiency (Wang et al., 2018; Zheng et al., 2018), analysis of industrial water use efficiency (Bao & Chen, 2017), urban water use efficiency (Feng et al., 2017; Guo et al., 2016) among others. But it is important to note that the underlying objective of such studies is to establish the trend of efficiency in the various study areas to highlight areas that are performing well and those that need to restructure their water management policies. Afterward, analyzing the possible water use efficiency determinants is key to formulating water use efficiency measures and implementing scenario analysis. For this reason, constructing water use efficiency models and introducing novel approaches to establish robust results and recommending viable strategies have been the core goals of water use efficiency studies.

Existing studies in West Africa, such as Zongo et al. (2017) and Yeleliere et al. (2018), have focused on optimizing water resources without considering water use efficiency and pressure on the water environment. Data envelopment analysis is widely used in empirical studies on water use efficiency, irrigation water use efficiency, and utility efficiency. This method has been widely employed to evaluate water use efficiency in China (Ding et al., 2019; Xu et al., 2019), Spain (Naroua et al., 2014a, b), Canada (De Haan, 2020), the USA (Donnelly & Cooley, 2015), and India (Fishman et al., 2015). Regarding studies on water use efficiency in Africa, Brettenny and Sharp (2016) conducted a study on the productivity of water services by South African municipalities by evaluating the service efficiency change over time using the Malmquist productivity index (MPI) analysis. The results showed that the annual average production decline over the three years was a product of technological change. Above all, Gidion et al. (2019) used the data envelopment analysis (DEA) to present a consistency analysis of the performance score method used by the Energy and Water Utilities Regulatory Authorities of Tanzania. The assessment showed that network DEA (NDEA) outperforms empirical methods and that regulators using the proposed

NDEA technique will benchmark utilities and water use efficiency under a yardstick competition regime and, at the same time, identify the most efficient and weak urban water utilities using pure variable values. However, no study on water use efficiency has yet been conducted in West Africa. Therefore, a DEA model using desired and undesired input–outputs based on Tone and Tsutsui (2010) is adopted as the focal exploration method to estimate water use efficiency for 11 countries in West Africa (WA) between 2007 and 2016.

Several factors, including urbanization, foreign direct investment, industrialization, trade openness, and human capital, have significantly influenced water use efficiency. Previous studies explored how water resources in West Africa are influenced (Yeleeiere et al., 2018; Zongo et al., 2017). However, none of the studies have employed the common correlated effect mean group (CCEMG) estimator to explore possible factors that affect water use efficiency in the context of West Africa. The CCEMG possesses several benefits: First, it is robust to cross-sectional dependence and slope heterogeneity across panels. Second, it does not require any short-run coefficients, and third, it solves the problem of biasness in a simple but powerful augmentation of the group-specific regression model. As reported earlier, no study has employed the CCEMG estimator to appraise the determinants of water use efficiency; authors of this research believe that the outcome of previous studies may have some form of limitations in the methods used. For this reason, it is highly appropriate to employ the CCEMG estimator to explore the determinants of water use efficiency.

Given the shortcomings mentioned earlier in previous studies, this study aims to examine the trend of water use efficiency and appraise its determinants in the sampled West African countries. The study used the dynamic slacks-based model to estimate the water use efficiency scores and the CCEMG to explore the effect of urbanization, FDI, industrialization, export, and literacy rate on water use efficiency in West Africa. This study is significant and contributes to the extant literature on water use efficiency: (1) It is the first study in West Africa that has considered total water use efficiency. For instance, Hayford (2018) only focused on agricultural water use efficiency without considering how other municipal sectors and industries influence water use efficiency in Ghana and Mali. Therefore, bringing to fore the state of total water use efficiency will help authorities in West African countries to know the areas that promote or retard water use efficiency. (2) One major natural resource that possesses economic value is water; thus, it is important to appraise the relationship between water use and the income levels of the countries under study. However, no study has been conducted in West Africa to this effect. Therefore, this study will contribute to the literature by exploring the link between the income levels of the study economies and water use efficiency in West Africa. It will also contribute to the literature by highlighting the effect of URB and FDI on water use efficiency in West Africa. (3) To the best of the authors' knowledge, this is the first study on water use efficiency that has considered the DSBM-DEA model together with the CCEMG econometric approach. This study offers several policy suggestions for sustainable water use efficiency and resources management in the sampled countries from West Africa.

The remaining sections of this paper are structured as follows: The literature review which guides the research is in Sect. 2. Section 3 comprises the methodology and data source for the study. Section 4 presents the empirical findings of the study. Discussion of the results is found in Sect. 5, whereas the conclusion and suggested policy implications are in Sect. 6 of the paper.

## 2 Literature review

In recent years, the global community's focus has been on how to reduce pollution and conserve quality water for sustainable use. Water use efficiency is a substantial part of sustainable economic growth, so Luo et al. (2018) hinted that the efficient use of water resources is the safest way to resolve the growing water crises, especially in emerging economies. Shi et al. (2015) investigated the impact of industrial transformation on water use efficiency in China. They reported that water use efficiency of the northwest region of China improved by optimizing industrial structure. Examining industrial water use efficiency, Dieter (2018) estimated water use in the USA in 2015. The study's outcome revealed a decline in water use by 5% of the total water withdrawals compared to 2010. Regarding agricultural water use efficiency, Ward et al. (2016), in their report to the World Bank, stated that almost all dryland zones in Africa are far from exploiting their (technical) agricultural water management potential. They added that many farming households were highly sensitive to soil moisture risk, and when irregular rainfall reduced crop yields, their livelihood became imperiled. However, after a range of techniques from simple, low-cost practices designed to capture and conserve rainfall and investment in large-scale irrigation systems were made available, the farmers cultivated their crops throughout the year. Also, Koech and Langat (2018) reviewed the advances, challenges, and opportunities in improving irrigation water use efficiency in Australia. Their outcome showed that improvements in irrigation infrastructure through modernization and automation have led to water savings. Hayford (2018) similarly evaluated water use efficiency in sorghum–pigeonpea using diversified cropping systems in marginal areas of Ghana and Mali. The outcome of his study showed an increase in yields for farms that employed irrigation methods in both countries. He, therefore, recommended that farmers who want to produce crops in the whole year should adopt water-efficient irrigation methods to increase farm yields and, at the same time, manage the water resources.

Previous studies by researchers and policymakers have proven that several indicators influence water use efficiency in both developing and developed countries. Some studies found that urbanization significantly affects water use efficiency (Feng et al., 2017; Jiang et al., 2013). There is no doubt that a rise in urban growth contributes to global water consumption. The urban population depends on available water resources for domestic, industrial, agriculture, and other ecological purposes such as tourism and entertainment (Flörke et al., 2018; Moglia, 2014). Ferror et al. (2014) examined water use efficiency and sanitation of 127 service providers in Brazil from 2003 to 2010. Their study showed a decrease in inefficiencies at the rate of 4.9% during the study period. Ma et al. (2016) explored the dynamic coupling of urbanization and water resources utilization systems in China from 2002 to 2014. Their findings indicated that urbanization improved the water resources systems during the study period, and to that effect, pollution of water bodies decreased. McGrane (2016) reviewed the impact of urbanization on urban water management. He reported that proper urban planning enhanced water conservation and efficient water use. Matveeva et al. (2018) also analyzed water use efficiency in Russia. Their study showed that as urbanization increased, the gross water use intensity decreased. They further explained that this decrease in water consumption was due to the introduction of new technologies, which secured higher rationalities in using water resources based on the circulating water systems and reduced the water losses incurred. Similarly, Cai et al. (2018) used a spatiotemporal analysis to explore the impacts of urbanization on water use and energy-related CO<sub>2</sub> emissions of residential consumption in China from 2003 to 2012. The

findings of their study revealed that urban residential water use was minimal compared to rural water use throughout the study period, an indication that water resources management has been a priority for urban dwellers.

However, some researchers found urbanization to harm the use efficiency of water resources (Cerqueira et al., 2020; Sharma, 2017). The World Water Assessment Programme (WWAP 2015) documented that the rise in urbanization negatively influences the dynamic global consumption of water resources. Bigelow et al. (2017) explored the effect of urbanization on water withdrawals in the Oregon state. Their findings revealed that an increase in population and economic growth led to a rise in water withdrawals. They explained further that increasing the people's living standards influenced their food consumption and other lifestyle activities that depended much on water resources. Also, Rashid et al. (2018) explained that urbanization could result in inefficient use of water resources since increased production leads to stress on the water resources. However, urbanization resulting in the introduction of water-efficient machinery adopted in homes, industries, and farmlands could contribute significantly to water use efficiency. Some studies have found urbanization to positively influence water use efficiency, while others report that urban growth harms the use efficiency of water resources (Bigelow et al., 2017; Cerqueira et al., 2020; Sharma, 2017). From the viewpoint of using data from the period 2003–2012 for the 34 provinces in China, a study conducted by Cai et al. (2018) found urbanization to have a pronounced adverse influence on WUE. That is, urbanization caused a greater proportionate change in water use during the study period. On the other hand, Balha et al. (2020) investigated the impact of urbanization on water resources in New Delhi from 2005 to 2016 and predicted how the situation will be in 2031. The outcome of their study showed that an increase in the urban population in the megacity of Delhi had a significant negative effect on ground-water abstraction. The reason was that more people were withdrawing groundwater for various purposes, causing stress to the water recharge. Thus, they predicted that by 2031, a 1km<sup>2</sup> increase in the built-up area would decrease groundwater recharge of rainfall by 0.3million cubic meters. The researcher, therefore, recommended the implementation of laws on the rate of water abstracted as the population in the megacity increase. It is not surprising that Yasmeen et al. (2020) report revealed a negative impact of urbanization on ecological efficiency in China at the national level.

Another strand of literature investigated the effect of foreign direct investment (FDI) on water use efficiency (Aust et al., 2019; FAO, 2017a; Kagohashi et al., 2015) and has shown mixed results ranging from the argument that foreign direct investment harms water resources consumption, to the fact that the introduction of new technologies and scientific knowledge through FDI has helped to enhance the efficient use of water resources (Akhmouch et al., 2018; Joshua & Bekun, 2020; Shahani et al., 2016; Yasmeen et al., 2020; Zhang et al., 2019). Okafor (2015) investigated the locational determinants of US outward FDI on 23 countries in SSA from 1996 to 2010. The outcome of their study revealed the introduction of sophisticated technologies for agricultural and industrial production in SSA due to FDI. Zheng et al. (2018) also applied a parametric distance function method to study provincial total-factor water use efficiency and its causes in China for the period 2000–2015. Their findings revealed that mechanisms used in the agriculture and industrial sectors through FDI had desired influence on water use efficiency. Ding et al. (2019) also investigated the effect of environmental directives, groups of FDI, and water use efficiency centering on the dual regulatory arrangements on the Yangtze River Economic Belt from 2006 to 2016. In employing the SE-SBM model, Ding et al. (2019) showed that FDI significantly improved water use efficiency through environmental regulations and technological innovations implemented by foreign investors. In addition, Zhang et al. (2019) explored the

effects of FDI on the efficiency of the government's expenditure on environmental protection in China using data envelopment analysis. Their research showed that FDI positively correlated with the efficiency of government environmental expenditure in terms of quality and quantity spending, which resulted in a positive spillover effect. Moreover, Yasmeen et al. (2020) explored the impact of technological innovation, environmental regulations, and urbanization on the ecological efficiency of China in the context of COP21 using data from 2008 to 2018. The outcome of their study showed that technological innovation had a significantly positive influence on ecological efficiency at both national and regional levels. On the other hand, other studies found FDI to have a negative effect on water resources and water resources efficiency. For instance, Zomorodi et al. (2017) assessed the impact of FDI on environmental quality in China from 2003 to 2014. The study's outcome revealed some form of a negative relation between FDI and air and water pollutant emissions. Therefore, they suggested that environmental regulations in all regions should focus on foreign firms to use the latest technologies to reduce environmental pollution. A study by Jun et al. (2018) appraised the influence of FDI on wastewater discharge in China for the period 1982 to 2016. Their findings revealed that FDI caused pollution for the entire period. They further highlighted that increased water withdrawal for production to increase their revenue results in water stress. Adding up, Jain and Chetty (2019) reported on a global scale that although FDI has some benefits to the host countries, it has contributed to wastewater discharged into most river bodies leading to the extinction of both flora and fauna and the numerous water-related health diseases.

Conceivably, the export of goods and services is a major means of increasing a nation's income. The authors thus explored the role of trade openness in the form of export and import as a determinant of water use efficiency in extant literature. For example, the outcome of a study conducted by Deng et al. (2015) revealed that virtual water export had caused inadequate access to potable water in some host industrial cities in China. Also, Zheng et al. (2018) re-examined the regional total-factor water efficiency and its determinants in China from 2000 to 2015 using a parametric distance function approach. They reported that import and export trade positively influenced water use efficiency in China during the entire study period. On the contrary, Wang et al. (2014) said that virtual water export significantly affected the country's quality and quantity of water resources when they examined the relationship between regional economic sectors and water use in a water-scarce area in China over the period 1997–2007. Wang et al. (2018) also indicated how some high export-dependence provinces in China suffered high water dependency and recommended that those regions learn from provinces with high water use efficiency. It is therefore very important to minimize the production of water-intensive products in areas with low water supply.

Furthermore, this research accessed extant literature on the relationship between industrial activities and water use efficiency. Piao et al. (2010) investigated climate change and its linkage with water resources and agriculture in China. Their study showed that the drastic drop in the amount and value of water resources due to climate variability emanated from the industries. Shang et al. (2016) investigated the influencing factors of industrial water use changes in Tianjin and their impact assessment. Their outcome indicated that water use efficiency for the industries declined between 2003 and 2008 but gained stability from 2008 to 2012. They added that industrial restructuring not aimed at efficient water use has a relatively weak influence on industrial water use. Wang et al. (2018) also reported the negative impact of industrial structure on water use efficiency in China. Thus, they iterated that the negative relationship could be related to industrial enterprises lacking adequate water-saving technologies. In addition, Zameer et al. (2020) explored the coordinated development of natural resources, financial

development, and ecological efficiency. Their findings highlighted how industrial activities contribute to environmental pollution. Moreover, Ma et al. (2020) studied how pollution exacerbates China's water scarcity and regional inequalities. The findings revealed that in China, untreated wastes from industrial activities discharged into nearby water resources negatively impact the quality and quantity of the water resource.

Various studies have proven the positive effects of education (both formal and informal) on water use (Joshi & Amadi, 2013; Kobzev Kotásková et al., 2018). Wang et al. (2018) investigated the relationship between water use efficiency and its inducing elements in China from 2008 to 2016 using the DEA-Tobit model. The study established a significant association between literacy rate and water use efficiency (WUE). A similar study was conducted by Kobzev Kotásková et al. (2018) in India from 1975 to 2016 on the role of education on women. Their findings indicated a significant influence of education on economic growth and women's finances, implying that educated women can afford better water-efficient products in their homes and farms. In addition, Joshi and Amadi (2013) assessed the effect of water, hygiene interventions, and sanitation on enhancing effective and healthy conditions among children in school, and one of the commendable aspects of their results was the children's interest in handwashing practices and how they managed the little water provided to them by the school. On the other hand, in a discussion paper, Proudfoot and Kelley (2017) pointed out that technological advancement through an increase in education can harm the environment, including water resources. In their report on 'can technology save the planet?', they explained that through an increase in education, people learn how to manufacture equipment and chemicals that pollute the environment and water resources. Also, Rustam et al. (2020) revealed the non-responsiveness of educational institutions toward eco-friendly activities in Pakistan. However, Desha et al. (2015) and Ma et al. (2019) attested that people with enhanced literacy are often conscious of their environment. Hence, they adhere to environmental regulations and protect natural resources.

From the above review of literature, existing studies have reported on the trend of total water use efficiency, especially in China, and the diverse ways that urbanization, FDI, export, industrial activities, and education have influenced the state of water use efficiency. Authorities in West African countries have not paid keen attention to the efficient use of water resources, and authors of this study are of the view that it is very important to consider the determinants as mentioned above of water use efficiency, among others, when formulating policies concerning sustainable water resources management in the respective countries. This study is different from previous researches and also fill the research gap because while studies such as Nafchi (2016); Wang et al. (2018); and Zhang et al. (2019) used sewage as the bad output when calculating the water use efficiency scores, this study adopted water stress as the undesired output due to unavailability of data on wastewater or sewage for most African countries. Also, in exploring the effect of urbanization and FDI on water use efficiency in West Africa, the authors applied the CCEMG panel estimator because of its robustness to cross-sectional dependence and slope heterogeneity. Moreover, this is the first study to employ the DSBM and an advanced panel technique such as the CCEMG in West Africa. The study period is from 2007 to 2016 for 11 countries in West Africa due to data limitations for the remaining countries in West Africa.

### 3 Materials and methods

This section of the study discusses the model specification of water use efficiency, and its data source, model specification for the effect of urbanization, and foreign direct investment on water use efficiency and their source of data, descriptive statistics, and the econometric approaches through which derive the long-run estimation parameters were derived.

#### 3.1 Model specification for water use efficiency

Several researchers have used ratio analysis and stochastic frontier methods to analyze water use efficiency over the years (Wang et al., 2018). However, DEA is an effective way of evaluating different inputs and outputs of decision-making units. It adopts effective samples without posing any issue of invalid series or unreliable weights. Models such as the Malmquist productivity index and the window analysis model are known for their strength in taking into account time change effects. Still, some studies ignore issues of carryover activities linking two continuous periods (Zhang et al., 2019). Thus, the dynamic model proposed by Fare and Grosskopf (1997) solves the problem of carry-over among study series because the dynamic model contains functional aspects of production fixed into the conventional BCC DEA model. However, the dynamic DEA went through several transformations until Tone and Tsutsui (2010) incorporated the slacks-based model into the dynamic DEA to be the dynamic slacks-based model (DSBM).

This study used the dynamic SBM-DEA method of Tone and Tsutsui (2010) because of its ability to consistently manage the desired inputs, desired outputs, unwanted outcomes, and carryover elements separately. Adopting this model establishes that, regardless of the operating level, this approach has a great deal of capacity to allocate weights to each indicator easily. The forms of correlation elements in a dynamic SBM system are free, set, good, and bad. For this cause, our research adopted gross domestic product per capita (GDPPC) as the index variable that links the two consecutive years of output. In our study, this approach is relevant because it will enable West Africa countries and other countries to realize the importance of incorporating water resources management in national economic policies.

This extensively studied analysis suggests that individual cross sections are set at  $n$  DMUs ( $\emptyset = 1, \dots, n$ ) over  $T$  periods for  $t = 1, \dots, T$  with the panel. For each period, the DMUs have  $p$  inputs such that ( $\mu = 1, \dots, p$ ),  $q$  outputs such that ( $\mu = 1, \dots, q$ ), and  $k$  desirable outputs such that ( $\mu = 1, \dots, l$ ). Setting  $x_{\mu\emptyset t}(\mu = 1, \dots, p)$ ,  $y_{\mu\emptyset t}(\mu = 1, \dots, q)$ ,  $x_{\mu\emptyset t}^{\text{bad}}(\mu = 1, \dots, k)$  and  $y_{\mu\emptyset t}^{\text{good}}(\mu = 1, \dots, l)$  indicate the observed (desirable) input and desirable output values of DMU at term  $t$ . Furthermore, the symbolization of the desirable link is denoted as  $m_{\mu\emptyset t}^{\text{good}}$ . Thus, we assume  $m_{\mu\emptyset t}^{\text{good}}(\mu = 1, \dots, ngood; \emptyset = 1, \dots, n; t = 1, \dots, T)$ , where  $ngood$  is the number for the desirable link. The analysis considers ten consecutive seasons, each of which is defined by input and output variables, in which the carryover connects two-year terms at the same time. Reformulated from Tone and Tsutsui (2010), Fig. 1 shows the complex model of the production function in 10 consecutive years.

According to Tone and Tsutsui (2010), the production possibility which denotes  $\{x_{\mu t}\}$ ,  $\{y_{\mu t}\}$ , and  $\{m_{\mu t}^{\text{good}}\}$  is correspondingly given the relations;



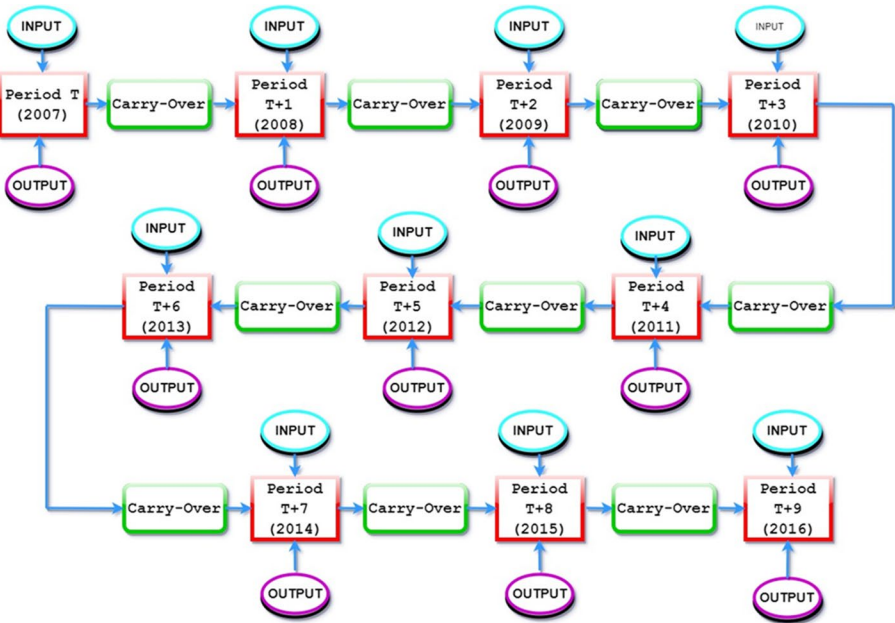


Fig. 1 The dynamic structure of production function among link, period, input, and output

$$\begin{aligned}
 x_{\mu t} &\geq \sum_{\emptyset}^n x_{\mu\emptyset t} \theta_{\emptyset}^t, (\mu = 1, \dots, p; t = 1, \dots, T) \\
 y_{\mu t} &\leq \sum_{\emptyset}^n y_{\mu\emptyset t} \theta_{\emptyset}^t, (\mu = 1, \dots, q; t = 1, \dots, T) \\
 m_{\mu t}^{\text{good}} &\leq \sum_{\emptyset}^n m_{\mu\emptyset t}^{\text{good}} \theta_{\emptyset}^t, (\mu = 1, \dots, \text{ngood}; \emptyset = 1, \dots, n; t = 1, \dots, T)
 \end{aligned}
 \tag{1}$$

for  $\theta_{\emptyset}^t \geq 0, (\emptyset = 1, \dots, n; t = 1, \dots, T), \sum_{\emptyset}^n \theta_{\emptyset}^t = 1, (t = 1, \dots, T)$  and  $\emptyset^t \in R^n$  where  $\emptyset^t \in R^n (t = 1, \dots, T)$  refers to the intensity vector for period  $t, x_{\mu\emptyset t}, y_{\mu\emptyset t}$ , and  $m_{\mu\emptyset t}^{\text{good}}$  on the right side of Eq. (1) are affirmative information representing the constant returns-to-scale, whereas  $x_{\mu t}, y_{\mu t}$ , and  $m_{\mu t}^{\text{good}}$  on the left are elements that are connected by the intensity variable  $\theta_{\emptyset}^t$ .

When we continue to link (carryover) between period  $t$  and  $t + 1$ , then the following conditions must be met:

$$\sum_{\emptyset}^n z_{\mu\emptyset t}^{\beta} \theta_{\emptyset}^t = \sum_{\emptyset}^n z_{\mu\emptyset t}^{\beta} \theta_{\emptyset}^{t+1}, \forall (\mu : t = 1, \dots, T - 1)
 \tag{2}$$

where  $\beta$  represents a good link. Further having  $DMU_g (g = 1, \dots, n)$  and utilizing the production is therefore expressed as:

$$\begin{aligned}
 x_{\mu gt} &= \sum_{\theta=1}^n x_{\mu\theta t} \theta_{\theta}^t + v_{\mu t}^{-}, (\mu = 1, \dots, p; t = 1, \dots, T) \\
 y_{\mu gt} &= \sum_{\theta=1}^n y_{\mu\theta t} \theta_{\theta}^t - v_{\mu t}^{-}, (\mu = 1, \dots, p; t = 1, \dots, T) \\
 m_{\mu gt}^{\text{good}} &= \sum_{\theta=1}^n m_{\mu\theta t}^{\text{good}} \theta_{\theta}^t - v_{\mu t}^{\text{good}}, (\mu = 1, \dots, \text{ngood}; t = 1, \dots, T)
 \end{aligned} \tag{3}$$

for  $\sum_{\theta}^n \theta_{\theta}^t = 1, (t = 1, \dots, T), \theta_{\theta}^t \geq 0, v_{\mu t}^{-} \geq 0, v_{\mu t}^{+} \geq 0$  and  $v_{\mu gt}^{\text{good}} \geq 0$  where  $v_{\mu t}^{-}, v_{\mu t}^{+}$  and  $v_{\mu gt}^{\text{good}}$  are referred to as slack variables, defined as input excess, output shortfall, and good link shortfall. Therefore, the overall efficiency of the *DMUs* is computed with the variables which include  $\theta^t, v_t^{-}, v_t^{+}$ , and  $v_t^{\text{good}}$ . The output-oriented overall score is then calculated using the following relation expressed as:

$$\frac{1}{\Phi_g^*} = \max \frac{1}{T} \sum_{t=1}^T \omega^t \left[ 1 + \frac{1}{v + \text{ngood}} \left( \sum_{\mu=1}^p \frac{\omega_{\mu}^{+} v_{\mu gt}^{+}}{y_{\mu gt}} + \sum_{\mu=1}^{\text{ngood}} \frac{v_{\mu gt}^{\text{good}}}{m_{\mu gt}^{\text{good}}} \right) \right] \tag{4}$$

Considering Eq. (2) and Eq. (3), the weight of period  $t$  and input  $\mu$  is denoted as  $\omega^t$  and  $\omega_{\mu}^{+}$ , and both must satisfy the condition below:

$$\sum_{\mu=1}^v \omega_{\mu}^{+} = v \tag{5}$$

Notably, when performance decreases because they have similar feature outputs, shortcomings in the desirable connection are given (Tone, 2011). On the other hand, the good relationship plays a role in linking two sequential years, as shown by the restrictions. Therefore, the effectiveness of the particular duration  $t$  is determined by the relative slack of the outcomes and connections. By an optimal solution of  $(\{\theta_{gt}^{t*}\}, \{v_{gt}^{-*}\}, \{\theta_{gt}^{+*}\}, \{v_{gt}^{\text{good}*}\})$ , the efficiencies are then estimated using the formula:

$$\Phi_{gt}^* = \frac{1}{\left[ 1 + \frac{1}{v + \text{ngood}} \left( \sum_{\mu=1}^p \frac{\omega_{\mu}^{+} v_{\mu gt}^{+*}}{y_{\mu gt}} + \sum_{\mu=1}^{\text{ngood}} \frac{v_{\mu gt}^{\text{good}*}}{m_{\mu gt}^{\text{good}}} \right) \right]}, t = 1, \dots, T \tag{6}$$

### 3.2 Data source

The decision-making units (DMUs) for this study were five input and output variables, namely total water use ( $W$ ), capital stock ( $C$ ), and labor ( $L$ ) are the input variables; economic growth ( $E$ ) is the desired output variable, while water stress ( $S$ ) is the undesired output. Previous research (Zheng et al., 2018) integrated residential, commercial, agricultural, and ecological water to reflect the overall use of water. The report further compiled overall residential, commercial, and agricultural 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 a proxy for economic growth in terms of outputs. Labor, capital, and water use in a production process contribute to a rise in GDP. However, the intense abstraction of water supplies puts pressure on the available water resources and consequently

contributes to water stress, which is the unwanted output variable in this analysis. All variables employed in our research were derived from the World Bank development indicators (WDI, 2019), and the duration is 2007–2016. Other factors like total wastewater and water price could have been used, but countries in West Africa have inadequate information on the variables above. Therefore, the total number of sampled countries, variables used, and duration for the study were due to data availability. Table 1 is a summary of the source of information and the elements employed.

### 3.3 The nexus of water use efficiency, urbanization, and foreign direct investment

Studies have shown that apart from the input and output factors of water use efficiency, other determinants also influence the efficiency of water use (Cerqueira et al., 2020; Deng et al., 2015; Ding et al., 2019; Proudfoot & Kelley, 2017; Wang et al., 2018). Since the DMUs of the study are further classified into subpanels as lower middle income (LMI) and low income (LI), the CCEMG estimator was employed to explore the long-run relationship between water use efficiency and urbanization and FDI in West Africa.

#### 3.3.1 Model specification

Studies have shown that the quest to secure better employment opportunities, access to better food, healthcare, and lifestyle has caused people to migrate from rural to urban areas of several West African countries (Sun et al., 2021). This increase in urbanization causes a lot of environmental insults, including a decrease in water quality and quantity. The reason is that most countries in Africa do not have the required logistics and capacity to ensure the efficient use of water resources (Abubakar, 2018). The exponential rise in urbanization has led to increased activities by the agricultural and industrial sectors (IND) who produce not only for the consumption of the host country but export to other countries. According to Wang et al. (2018), the increase in the exploitation of water to feed these sectors mentioned above causes stress on the available water resources. However, Ma et al. (2019) believe that a good part of the population who are enlightened can put measures in place to ensure efficient use of water in their homes, farms, and factories. Also, through FDI, multinational companies employ new technologies and experts who can use few volumes of water to produce more goods and services to ensure efficient use of water in those industrial and agricultural sectors. Grounded on the theoretical background explained above, this study proposed a model that comprises six variables, that is, urbanization (URB), foreign direct

**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
Carryover	GDPPC	Millions of US Dollars	WDI

WDI world development indicators

investment (FDI), industrial activities (IND), export (EX), and literacy rate (LIT) as the explanatory variables, while water use efficiency (WUE) is the explained variable; IND, EX, and LIT are used as control variables to resolve the issues of omitted variable bias. The following panel model is proposed for estimation based on the series as mentioned earlier:

$$WUE_{it} = \beta_0 + \beta_1 URB_{it} + \beta_2 FDI_{it} + \beta_3 IND_{it} + \beta_4 EX_{it} + \beta_5 LIT_{it} + \varepsilon_{it} \quad (7)$$

where WUE represents water use efficiency, URB, FDI, IND, EX, and LIT are urbanization, foreign direct investment, industrial activities, export and literacy rate correspondingly;  $\beta_0$  is the constant term, whereas  $\beta_1 - \beta_5$  are slope coefficients measuring the elasticities of water use efficiency (WUE) concerning the afore-stated model regressors;  $\varepsilon_{it}$  represents the error term assumed to be normally distributed with a mean of zero and a variance of  $O^2$ ;  $i$  denotes the individual countries within the study panel; and  $t$  is the study period (2007–2016). To minimize the issues of data fluctuations and heteroscedasticity, natural logarithms of the independent variables were taken. As stated by Sinha and Shahbaz (2018), findings from log-linear models are more consistent than basic linear models and generate reliable estimates. Zaidi et al. (2019) also made it clear that, compared to a simple linear transformation model, a model in a log-linear framework yields consistent and reliable outcomes empirically. Based on these views, Eq. 7 was transformed into a log-linear form as:

$$WUE_{it} = \beta_0 + \beta_1 \ln URB_{it} + \beta_2 \ln FDI_{it} + \beta_3 \ln IND_{it} + \beta_4 \ln EX_{it} + \beta_5 \ln LIT_{it} + \varepsilon_{it} \quad (8)$$

where  $\beta_0 - \beta_5$ ,  $\varepsilon_{it}$ ,  $i$ , and  $t$  are already defined in Eq. 1;  $\ln URB$ ,  $\ln FDI$ ,  $\ln IND$ ,  $\ln EX$ , and  $\ln LIT$  are the transformed natural logs of URB, FDI, IND, EX, and LIT, respectively. According to Sun et al. (2021), estimated coefficients are interpreted as elasticities after variables have been transformed into logarithms. With that,  $\beta_1$  was expected to have a negative influence on water use efficiency, and  $\beta_2$  was assumed to have a positive impact on water use efficiency. This study anticipates that the control variables ( $\beta_3$ ,  $\beta_4$ , and  $\beta_5$ ) may have either a negative or positive effect on water use efficiency.

### 3.3.2 Data and descriptive statistics

The study used panel data of 11 West African countries (Benin, Burkina Faso, Cote D'Ivoire, Ghana, Liberia, Mali, Mauritania, Niger, Nigeria, Sierra Leone, and Togo) over the period, 2007 to 2016. Musah et al. (2020) have shown that these selected countries are highly heterogeneous in their financial, political, geographic characteristics, and cultural structures. This served as a basis for the authors to perform thorough research using the independent variables since variations exist. As indicated in Table 2, the variables employed for the study are derived from the World Development Indicators (WDI, 2019).

Table 3 presents the descriptive statistics of the variables in the various panels. From the main panel, EX had the highest mean ( $M$ ) value of 21.91250 and a standard deviation (SD) of 1.534926. The next were IND ( $M=21.54975$ ,  $SD=1.694727$ ), FDI ( $M=19.86646$ ,  $SD=1.436267$ ), URB ( $M=15.49314$ ,  $SD=1.057382$ ), LIT ( $M=3.779326$ ,  $SD=0.312362$ ), and WUE ( $M=0.627203$ ,  $SD=0.360044$ ). In the lower-middle-income (LMI) panel, EX recorded the highest mean ( $M$ ) value of 23.07656 with a standard deviation (SD) of 1.3815. Followed by EX are IND ( $M=22.73634$ ,  $SD=1.424962$ ), FDI ( $M=20.46567$ ,  $SD=1.628027$ ), URB ( $M=16.09655$ ,  $SD=1.270777$ ), LIT ( $M=3.934585$ ,  $SD=0.262068$ ), and WUE ( $M=0.610105$ ,  $SD=0.337177$ ). Finally, with regard to the

**Table 2** Definition of variables and data source

Variable	Definition	Source
WUE	Total water use efficiency	Authors own calculation of DSBM
URB	Urban population, total	WDI
FDI	Foreign direct investment (Net inflows %)	WDI
EX	Export of goods and services (Constant 2010 US\$)	WDI
IND	Industry, value-added	WDI
LIT	Literacy rate	WDI

*DSBM* dynamic slacks-based model, *WDI* world development indicators

**Table 3** Descriptive statistics

Panel	Statistics	WUE	FDI	EX	IND	URB	LIT
Main	Mean	0.627203	19.86646	21.91250	21.54975	15.49314	3.779326
	Std. dev	0.360044	1.436267	1.534926	1.694727	1.057382	0.312362
	Skewness	-0.083780	-0.035796	0.748077	0.04019	0.332134	0.050314
	Kurtosis	1.272448	3.282274	3.293464	3.351698	4.142471	1.944840
LMI	Mean	0.610105	20.46567	23.07656	22.73634	16.09655	3.934585
	Std. dev	0.337177	1.628027	1.3815	1.424962	1.270777	0.262068
	Skewness	0.138818	-0.701056	0.583967	0.913823	0.360417	-0.153825
	Kurtosis	1.340045	3.783793	2.112471	2.467060	2.194590	2.322438
LI	Mean	0.641452	19.36711	20.94245	20.56092	14.99029	3.649944
	Std. dev	0.379807	1.42092	0.813322	1.196028	0.396029	0.292585
	Skewness	-0.236942	-0.139148	-0.594976	-0.420180	0.581360	0.433354
	Kurtosis	1.252139	2.819988	2.232581	1.911845	2.471256	1.981313

*LMI* and *LI* lower-middle-income and Low-income countries, respectively

low-income (LI) panel, EX had the highest mean ( $M$ ) of 20.94245 and a standard deviation (SD) of 0.813322 followed by IND ( $M=20.56092$ ,  $SD=1.196028$ ), FDI ( $M=19.36711$ ,  $SD=1.42092$ ), URB ( $M=14.99029$ ,  $SD=0.396029$ ), LIT ( $M=3.649944$ ,  $SD=0.292585$ ), and WUE ( $M=0.641452$ ,  $SD=0.379807$ ).

Westfall (2014) has opined that with a skewness value of 0 and a kurtosis value of 3, a series is said to be normally distributed. Thus, the study realized that the distributions of WUE and FDI had negative skew for the main panel, but EX, IND, URB, and LIT were positively skewed. In the same panel, the allocations of FDI, EX, IND, and URB recorded enlarged tails with positive excess kurtosis, while WUE and LIT had small tails of kurtosis. For the LMI panel, WUE, EX, IND, and URB were positively skewed, whereas FDI and LIT were negatively skewed. Apart from FDI with a positive excess kurtosis, the remaining variables recorded kurtosis of thinner tails ( $K < 3$ ). Finally, with the LI panel, WUE, FDI, EX, and IND were found on the right side of the normal curve. However, URB and LIT were positively skewed. A report on the kurtosis showed that the distributions of all the variables had thinner tails of kurtosis less than 3. This result means that the skewness and kurtosis values for the variables dispersed across all the panels do not meet the conditions

for normal distribution. This result agrees with the Jarque–Bera normality test in Table 4, which also depicts a viable witness to reject the null hypothesis that the observed variables are normally distributed.

From the works of Zuur et al. (2010), and Kock and Lynn (2012), variables of high correlation may result in unreliable estimations leading to inferences of extreme biases. Therefore, a multicollinearity test was conducted to ascertain whether the variables were interdependent or not, as displayed in Table 4, all the series employed had VIFs below 10. Similarly, the test for the degree of tolerance for all explanatory variables was more than 0.2, indicating no multicollinearity issues. This finding suggests that it is statistically appropriate to employ URB, FDI, EX, IND, and LIT for the study's empirical analysis.

### 3.4 Econometric approaches

According to Sun et al. (2021), every panel data need to go through specific stages before achieving the desired objective. Therefore, the following econometric tests were performed to reach the final empirical analysis of the study.

- It is evident that economic integration exists among countries in West Africa, and there could be a level of cross-sectional reliance among the selected countries. Thus, Peseran's CD test is performed to determine whether cross-sectional dependence and homogeneity issues exist in the series. According to Mensah et al. (2019), testing for

**Table 4** Data normality and multicollinearity test

Panel	Variable	Data normality test		Multicollinear-ity test	
		Jacque–Bera	Probability	VIF	Tolerance
Main	WUE	16.56881	0.000252***	–	–
	URB	46.21959	0.000000***	2.52	0.396825
	FDI	0.466421	0.791987	1.85	0.540418
	EX	12.78526	0.001674***	1.30	0.769230
	IND	4.360828	0.112995	2.48	0.403225
	LIT	6.179192	0.045520**	1.34	0.746268
LMI	WUE	7.081328	0.028994**	–	–
	FDI	6.450620	0.039743**	3.34	0.299401
	URB	2.920716	0.232153	2.38	0.420168
	EX	5.379442	0.067900*	3.08	0.324675
	IND	9.060787	0.010776***	1.78	0.561797
	LIT	1.384346	0.500487	1.69	0.591715
LI	WUE	9.838751	0.007304***	–	–
	URB	4.894458	0.086533*	3.38	0.295882
	FDI	0.329560	0.848080	1.06	0.943396
	EX	6.014745	0.049421**	3.17	0.315457
	IND	5.670856	0.058693**	4.03	0.248138
	LIT	5.366719	0.068333*	1.49	0.670578

\*\*\*, \*\*, and \*Indicate 1%, 5%, and 10%, respectively

the problems of residual cross-sectional dependence and homogeneity serves as a vital basis for the selection of further econometric tests.

- Based on the studies of Sun et al. (2021) and Musah et al. (2020), there is a high possibility of cross-sectional dependence amid the study series. Therefore, the cross-sectional IPS (CIPS) together with the cross-sectional ADF (CADF) tests by Peseran (2007) was performed to explore the stationarity of the employed series. As cited in Sun et al. (2021), when a series has a unit root, the differenced test is performed to determine the stationarity of the series. However, when there is no unit root in the observed series, the data series is good enough for further regression analysis. Relying on the above hypothesis, this study showed no unit root since all the data series were not stationary at trend but proved to be stationary when the differenced test was done.
- Furthermore, the long-run estimations of the interlinkages among the variables were conducted using the common correlated effects mean group (CCMG) by Peseran (2006). The heftiness of the CCEMG estimator to cross-sectional dependence and heterogeneity makes it very expedient.
- To check the robustness of the CCEMG estimator, the dynamic common correlated effects mean group (DCCEMG) by Chudik and Pesaran (2015). The authors adopted this estimator because although studies such as Musah et al. (2020) have shown that the CCEMG estimator is efficient, it does not have the strength to inhabit the lagged explained variable while this is one of the properties of the DCCEMG. Chudik and Peseran (2015) emphasized that the DCCEMG estimator accommodates cross-sectional dependence and slope heterogeneity. Again, this robust estimator is applicable even in studies that have small data sizes.

### 3.5 Empirical results

This section presents the research-based results that helped to achieve the research objectives. The study seeks to analyze the trend of water use efficiency and investigate how urbanization and foreign direct investment affect the efficient use of water resources in the sampled West African countries. An important inference from an empirical study like this type is to estimate the long-run parameters of the explanatory variables once it is confirmed that the variables have long-run equilibrium.

### 3.6 Estimated results and discussions for water use efficiency

The MAXDEA ultra 8.17.1 software was used to explore the water use efficiency of the 11 countries in West Africa based on the DSBM-DEA approach proposed by Tone and Tsutsui (2010) as presented in Eq. 6. The Dynamic SBM-DEA model was employed to understand the changes in water use efficiency over time. Studies have shown that water consumption alone cannot be used as an input to generate a good output, such as an increase in economic growth, and have thus suggested the inclusion of other variables in the framework to achieve a good output. Since overexploitation of water resources could harm the ecosystem and the environment, it is necessary to include an undesired outcome. In this research, water stress was employed in the framework for analysis. The estimated results of the efficiency scores through the application of multiple inputs framework to derive the desired and undesired outputs are shown in Table 5. From the results, Benin, Burkina Faso, Liberia, Mauritania, and Togo were efficient with a score of 1.00. In contrast, Cote

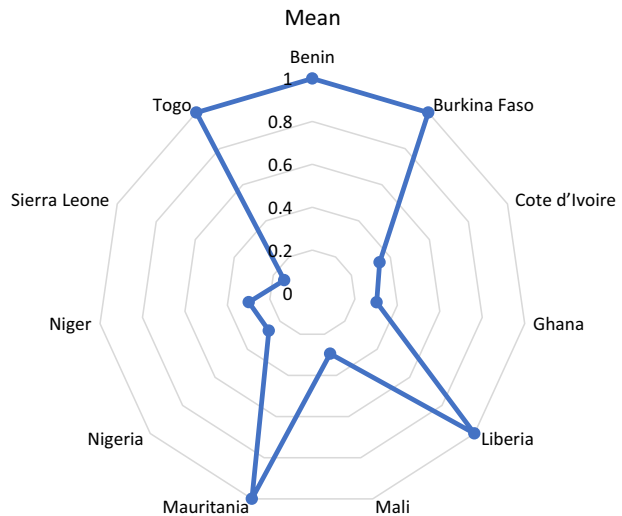
**Table 5** Estimates of the water use efficiency in West Africa. *Source:* Authors own calculation

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean
Benin	1	1	1	1	1	1	1	1	1	1	1
Burkina Faso	1	1	1	1	1	1	1	1	1	1	1
Cote d'Ivoire	0.073	0.363	0.453	0.331	0.328	0.437	0.435	0.412	0.473	0.631	0.345
Ghana	0.063	0.302	0.360	0.323	0.307	0.336	0.365	0.247	0.317	0.410	0.303
Liberia	1	1	1	1	1	1	1	1	1	1	1
Mali	0.039	0.248	0.326	0.236	0.246	0.246	0.287	0.332	0.362	0.627	0.295
Mauritania	1	1	1	1	1	1	1	1	1	1	1
Nigeria	0.066	0.274	0.306	0.290	0.262	0.321	0.286	0.270	0.266	0.343	0.268
Niger	0.030	0.302	0.348	0.263	0.274	0.332	0.310	0.297	0.297	0.540	0.299
Sierra Leone	0.099	0.128	0.177	0.140	0.129	0.146	0.143	0.150	0.167	0.156	0.144
Togo	1	1	1	1	1	1	1	1	1	1	1
Mean	0.488	0.602	0.634	0.599	0.595	0.620	0.621	0.610	0.626	0.703	0.605

d'Ivoire, Ghana, Mali, Nigeria, Niger, and Sierra Leone recorded efficiency scores below average.

The mean efficiency scores for the eleven selected countries experienced an unstable trend. The result shows that the overall mean efficiency score of 0.488 in 2007 increased to 0.634 in 2009 but declined to 0.595 in 2011. A rise in efficiency (0.620) was witnessed in 2012, although it fell again to 0.610 in 2014. However, a continuous surge in efficiency was observed until 2016 (0.703). In the later part of the study, this rise in efficiency scores could result from effective measures implemented by the authorities in the various West African countries, such as robust urban planning that promotes efficient water use. The result of the DSBM-DEA further shows that employing economic growth as the carryover variable to connect two continuous years had a negative influence on the total mean efficiency score (0.605), which is less than the optimal efficiency score of 1.00. Figure 2 is the graphical representation of the mean scores for each country.

**Fig. 2** Mean water use efficiency scores of selected countries in West Africa





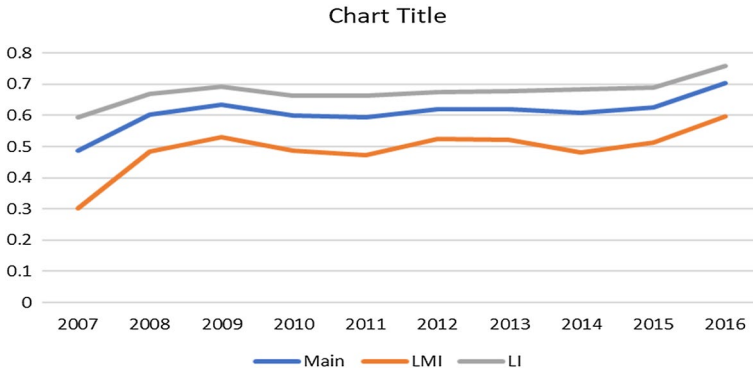


Fig. 3 Average efficiency scores of the sampled West African countries classified into income levels

Table 6 Cross-sectional dependence test

Main panel			LMI panel			LI panel		
Variable	CD-test	p-value	Variable	CD-test	p-value	Variable	CD-test	p-value
WUE	6.221 <sup>a</sup>	0.000	WUE	3.067 <sup>a</sup>	0.002	WUE	2.335 <sup>a</sup>	0.020
URB	25.677 <sup>a</sup>	0.000	URB	10.952 <sup>a</sup>	0.000	URB	9.714 <sup>a</sup>	0.000
FDI	5.467 <sup>a</sup>	0.000	FDI	4.434 <sup>a</sup>	0.000	FDI	13.405 <sup>a</sup>	0.000
EX	17.85 <sup>a</sup>	0.000	EX	7.433 <sup>a</sup>	0.000	EX	9.473 <sup>a</sup>	0.000
IND	14.088 <sup>a</sup>	0.000	IND	5.63 <sup>a</sup>	0.000	IND	7.747 <sup>a</sup>	0.000
LIT	17.127 <sup>a</sup>	0.000	LIT	6.597 <sup>a</sup>	0.000	LIT	9.553 <sup>a</sup>	0.000

<sup>a</sup>indicates the statistical significance at 1% level

The sampled countries were further grouped into income levels to ascertain if the trend of water use efficiency could be linked to income levels. The study gathered that countries in the low-income panel performed better than the lower-middle-income panels, although the trend looks the same. An increase in WUE was recorded from 2007 to 2009, but it dropped till 2011, whereas steady rise occurred until it fell again in 2014. Afterward, a steady surge occurred until 2016. The result is not surprising because a county like Togo had a population of just about 8,082,359 as of 2019, and the economy is dependent on rain-fed subsistence agriculture (WDI, 2019). A graphical representation of the income level groups for the study is shown in Fig. 3.

### 3.7 Estimated results of the linkage between WUE, URB, and FDI

#### 3.7.1 Cross-sectional dependence test results

Regarding the study’s empirical analysis, the cross-sectional dependence test was performed to ascertain the presence or absence of cross-sectional independence in the series. Obviously, economies within a particular panel could exhibit some form of dependencies as a result of economic integration and globalization. It is therefore important to explore appropriate tests that handle cross-sectional dependencies. As depicted in Table 6, the null

hypothesis of cross-sectional independence, which shows that the sampled countries do not have any correlation and thus exhibit mutual exclusiveness, was rejected against the alternative hypothesis that the countries rely on each other. This means that strong dependencies were established among the study panels; hence, the study employed econometric techniques that consider cross-sectional dependencies.

### 3.7.2 Panel unit root tests results

To determine the integration order of the study series, the cross-sectional IM Pesaran and Shin (CIPS) and cross-sectional augmented Dickey–Fuller (CADF) stationarity tests which perform efficiently in the presence of cross-sectional dependence were conducted. The outcome of the test, as shown in Table 7, revealed that the null hypothesis of non-stationarity for all the panels was accepted at levels, but at the first difference, the variables in all the panels were stationary. It was grounded on the results of the integration order that the model estimation techniques were adopted.

### 3.7.3 Model estimation test results

Table 8 presents the results of the common correlated mean group (CCMG) estimations regarding the long-run equilibrium amid WUE, URB, FDI, EX, IND, and LIT in WA countries classified into subpanels as the main panel, lower-middle-income economies, and low-income economies. The study's finding shows that the coefficients of URB in the main and

**Table 7** CIPS and CADF unit root test results

Panel	Variable	CIPS				CADF			
		Level	Dec.	First diff	Dec.	Levels	Dec.	First diff.	Dec.
Main Panel	WUE	-0.975	I(0)	-2.772*	I(1)	-0.211	I(0)	-3.750***	I(1)
	URB	-1.716	I(0)	-2.879**	I(1)	-1.938	I(0)	-3.434***	I(1)
	FDI	-2.537	I(0)	-4.213***	I(1)	-2.583	I(0)	-2.776*	I(1)
	EX	-1.755	I(0)	-3.485***	I(1)	-2.425	I(0)	-2.699*	I(1)
	IND	-2.437	I(0)	-2.970**	I(1)	-2.555	I(0)	-2.795*	I(1)
	LIT	-2.170	I(0)	-2.835**	I(1)	-2.134	I(0)	-2.765*	I(1)
LMI	WUE	-1.532	I(0)	-2.995**	I(1)	-0.813	I(0)	-3.485***	I(1)
	URB	-0.745	I(0)	-3.023***	I(1)	-0.100	I(0)	-2.835**	I(1)
	FDI	-2.400	I(0)	-4.144***	I(1)	-2.339	I(0)	-2.437***	I(1)
	EX	-2.102	I(0)	-2.795*	I(1)	-2.219	I(0)	-3.520***	I(1)
	IND	-2.059	I(0)	-2.849**	I(1)	-2.107	I(0)	-3.341***	I(1)
	LIT	-2.214	I(0)	-2.711*	I(1)	-2.386	I(0)	-3.139***	I(1)
LI	WUE	-0.572	I(0)	-4.816***	I(1)	-0.421	I(0)	-3.582***	I(1)
	URB	-2.507	I(0)	-2.891**	I(1)	-2.520	I(0)	-3.571***	I(1)
	FDI	-2.084	I(0)	-3.582***	I(1)	-1.001	I(0)	-2.949***	I(1)
	EX	-1.726	I(0)	-2.690*	I(1)	-2.286	I(0)	-2.758*	I(1)
	IND	-2.498	I(0)	-2.937**	I(1)	-2.167	I(0)	-2.723*	I(1)
	LIT	-1.202	I(0)	-2.987**	I(1)	-2.043	I(0)	-2.868**	I(1)

\*\*\*, \*\*, and \* indicate 1%, 5%, and 10%

**Table 8** Panel model estimation results—CCEMG approach

Panel	Variable	Coefficient	Z-statistics	Probability
Main panel	URB	146.2412	1.02	0.007***
	FDI	0371401	2.11	0.035**
	EX	-0692647	-0.99	0.322
	IND	-0460127	-0.76	0.046**
	LIT	-1737236	-0.35	0.727
LMI	URB	41.76298	0.76	0.044**
	FDI	0429797	-0.86	0.092*
	EX	-1050017	-1.98	0.047**
	IND	-0052382	-0.03	0.074*
	LIT	4273438	0.13	0.094*
LI	URB	23.73659	1.55	0.121
	FDI	-0015683	-0.08	0.035**
	EX	8583482	1.19	0.234
	IND	-1.166631	-1.08	0.080*
	LIT	588416	1.52	0.128

\*\*\*, \*\*, and \* indicate 1%, 5%, and 10%

LMI panels were positive and statistically significant, but this was different in the LI panel because the coefficient was insignificant. The findings indicate that a unit change in URB will cause an increase in WUE in the main and LMI panel by 146.241% and 41.76298%, respectively, but URB had no measurable impact on WUE in the LI economies of WA. The insignificant effect of URB implies that a unit change in URB did not have any material effect on WUE in the LI countries of WA.

Again, FDI had a material influence on WUE in the main and LMI panels, but a tangible impact was found in the LI panel. This means that a percentage change in FDI in the economies of the main and LMI panels in WA will enhance WUE by 0.0371401 and 0.0429797, respectively, whereas a decrease of 0.0015683 will be found in the LI economies. The significant impact of FDI on WUE could be that the multinational companies (MNCs) in those countries are adopting water-efficient technologies that enhance the efficient use of water resources. Also, the impact of EX on WUE was immaterial in the main and LI panels, but a negative impact on WUE was recorded in the LMI panel. The negative effect of EX on WUE is an indication that with every one percent rise in EX of those countries, WUE decreases by -0.1050017. Regarding the main and LI panels, EX had no significant influence on WUE. This result implies that an increase in EX did not substantially impact the WUE of WA economies.

Furthermore, the estimated results of IND revealed a negative and statically significant impact on WUE across all study panels. The negative influence of IND on WUE indicates that a unit increase in IND decreased WUE by 0.0460127, 0.0052382, and 1.166631 in the main, LMI, and LI panels, respectively. This suggests that industrial activities have a substantial effect on sustainable water use and access to adequate and quality water resources. Finally, our result showed that the influence of LIT on WUE was statistically immaterial in the main and LI panels. However, a statistically strong and positive effect of LIT on WUE was found in the LMI panel. The insignificant effect of LIT on WUE implies that a surge in LIT did not have any substantive influence on the WUE of economies in the main and LI panels.

To avoid any biases in the results, this current research analyzed the robustness of the CCEMG estimation by employing the dynamic common correlated mean group (DCCEMG) estimator as presented in Table 9. Results of the long-run elasticities of the CCEMG in Table 8 and DCCEMG in Table 9 exhibit some level of consistency. For instance, URB, FDI, EX, and IND were significant, and LIT was insignificant in both estimations for the LMI panel. This consistency is in line with the theoretical assertion by Chudik and Pesaran (2015) that the DCCEMG long-run estimation technique is robust and clears any issues of bias inferences.

## 4 Discussion

The mean efficiency scores for the 11 sampled countries from West Africa showed that attaining water use efficiency is a challenge for the sampled countries. This is because only five countries (Benin, Burkina Faso, Liberia, Mauritania, and Togo) reached the efficiency frontier of 1.00. The economic implication for those countries with water-efficient scores could be that they have better infrastructure and policies that enable them to harness economic growth and, at the same time, bring activities that cause water stress to an acceptable and minimal level. Besides, the total mean efficiency score of 0.605 is below the efficiency frontier of 1.00, indicating that economic growth, which is used as the carryover variable to connect two continuous years, had a negative influence on the total mean efficiency score. This outcome is in line with the findings of Hsieh et al. (2019), who reported that out of 31 provinces of China, only 10 attained the efficiency score of 1.00. Again, our result has a close link with Zhang et al. (2019). They employed the DSBM to assess the

**Table 9** Panel model estimation results—DCCEMG approach

Panel	Variable	Coefficient	Z-statistics	Probability
Main panel	WUE <sub>t-1</sub>	-46266	-1.90	0.057**
	URB	7.15685	1.36	0.075*
	FDI	06058	2.26	0.024**
	EX	-42387	-2.78	0.004***
	IND	-0.52934	-0.43	0.012**
	LIT	-75374	-0.86	0.388
LMI	WUE <sub>t-1</sub>	06095	0.14	0.890
	URB	2.73689	2.01	0.044**
	FDI	01641	0.56	0.077**
	EX	-24961	-0.71	0.036**
	IND	-31562	-0.92	0.005***
	LIT	2.70001	2.30	0.019**
LI	WUE <sub>t-1</sub>	21604	0.76	0.445
	URB	3.49091	0.87	0.386*
	FDI	09714	1.24	0.216**
	EX	1.85463	0.10	0.429
	IND	-10002	-2.20	0.043**
	LIT	1.61187	1.42	0.156

\*\*\*, \*\*, and \* indicate 1%, 5%, and 10%

environmental efficiency of industrial water pollution in China. They observed that more than half of the 30 provinces had a decrease in their water efficiency scores. This signposts that attention to water use efficiency in West Africa needs to be prioritized to ensure sustainable water for all.

A further classification of the sampled West African countries into income groups showed that countries in the low-income group performed better than countries in the lower-middle group. Deduction from this finding could be that countries within the LMI panel do not have enough water-saving technologies and expertise to efficiently use water resources in the municipal, industrial, and agricultural sectors. For that matter, water use is not regulated to its maximum, which often results in inadequate access to the resource. For instance, Yeleliere et al. (2018) and Ngene et al. (2021) have reported that overexploitation of water resources, especially for mining purposes, is gradually degrading the quality of water resources in the LMI countries of West Africa, such as Nigeria, Ghana, and Cote d'Ivoire. Hence, examining the efficient use of water in these countries at a panel level provides the basis for further identifying relevant indicators that influence efficient water use. This will also help formulate applicable and innovative policies that will help to address water stress issues and promote sustainable water resources management. Our result aligns with Sun et al. (2021), who found that water resources are stressed in SSA. Also, the countries within the LI group in this study may have a moderate population and urban growth. The reason for efficient use of water in the LI group could be due to fewer agricultural activities which does not harm the available water resources, hence less pressure on those economies. For instance, WDI (2019) reported that most of the labor force in Togo depends on rain-fed subsistence agriculture.

The study revealed that URB enhanced water use efficiency in the main and LMI panels. Good urban planning leads to the adoption of innovative technologies and proper water management in the urban dwellings, ensuring efficient use of water resources. Therefore, urban planning policies that hold efficient water use should be promoted by authorities in West Africa since it will aid in conserving adequate and quality water for both humans and the ecosystem. This result agrees with Ma et al. (2016), who found a strong trend of WUE, especially in the urban areas of the eastern part of China. The result is also in line with Zheng et al. (2018), who identified a significant positive impact of URB on WUE in China. However, the present study's finding does not align with Bigelow et al. (2017), whose findings showed that urbanization led to increased water withdrawal in the Willamette Valley of Oregon. The insignificant effect of URB implies that a unit change in URB did not have any material impact on WUE in the LI countries of WA. This finding also contradicts the outcome of Ren et al. (2016), which revealed that there was an improvement in WUE among the 12 sampled cities in the Gansu province of China. Therefore, West African countries like Nigeria, Ghana, Cote D'Ivoire, among others, should strengthen their policies on urban planning to include water resources management.

Foreign direct investment accelerated water use efficiency in the main and LMI panels. In recent times, most MNCs are investing in research and development (R & D) of water resources management in the host countries. This research and development help the companies and institutions to acquire knowledge on new technologies and measures to use less water to produce more goods without compromising the quality and quantity of the resources. This positive and significant outcome of FDI on WUE supports the work of Okafor (2015), who reported that FDI has helped to introduce sophisticated technologies in Africa and thus having a technological and knowledge spillover effect on WUE. The result of the present study is also in line with the study of Awolusi et al. (2017), who found FDI to have a significant influence on the growth of African

countries. This study further supports Zhang et al. (2019), which reported that FDI improved the efficient use of water resources in China through the introduction of new water-efficient technologies as well as knowledge spillover from investing economies. However, the negative and statistically significant effect of FDI on WUE in the LI panel could infer that the activities of MNCs in low-income countries of West Africa, such as overexploitation of both ground and surface water for various production processes, deteriorate the water resources. Notably, The World Bank Enterprise Survey (2013) has shown that about 720 firms in Ghana belong to foreign nationals, especially those in the mining sector. The outcome of this study aligns with Duncan (2020), who reported that illegal mining had polluted most water bodies in Ghana, including the Fena river in the Ashanti region, and he added that some of these illicit activities were supported by foreigners, mostly from China. This assertion also corresponds to the study by Zomorodi and Zhou (2017), who found a significant negative effect of FDI inflows on the condition of water in China.

In addition, export had a negative influence on water use efficiency. Due to the increase in the exportation of water-intensive products, there is a decrease in water supply in most West African countries. At the same time, much pressure is exerted on the equipment used to purify the water for various consumption purposes. Thus, the more water-intensive products are exported from LMI economies, and appropriate mechanisms to reduce stress on the available water resources are not implemented, the lesser the water use efficiency. Export also contributes to economic growth; however, it should not be detrimental to efficient water use. This finding supports the work of Wang et al. (2014), who report that the export of virtual water significantly affected the volume of water resources within China during the study period. Similarly, Vos and Boelens (2016) highlighted how virtual water trade negatively impacts global water resources. Contrary to our findings, Zheng et al. (2018) reported that import and export trade had positive returns on water use efficiency in China from 2000 to 2015. That notwithstanding, export did not significantly influence water use efficiency in the main and LI panels. This suggests that export did not have much correlation with efficient use of water in the sampled economies. However, this finding of our study does not align with the study conducted by Deng et al. (2015), which confirmed that the export of virtual water has a substantial influence on water resources in the industrial cities of China.

Industrial activities had a profound influence on water use efficiency in all the study panels. Evidently, almost all industrial activities depend on water for production. As production surges, there is pressure on the water, which eventually affects the quality and quantity of the resource in West Africa. Also, in cases where industries have inadequate human and infrastructural capacities for enhancing water utilization, their efficient use is not secure. For this reason, authorities need to ensure that water demand management plans are instituted and adhered to by companies while those who defy these laws face the laws of the land. This will instill some discipline and enhance water use efficiency in all sectors. This result is in line with Cosgrove and Loucks (2015), who stated that expansion in the production and supply of goods and services had increased the pollution of many river bodies worldwide. Similar to the finding of this study, Ngoran et al. (2016) has attributed economic development in Africa to water and labor. This result of IND also agrees with Wang et al. (2018), whose finding showed that IND negatively impacts water use efficiency in China. The result further aligns with Yeleliere et al. (2018), who found that the leading cause of poor water quality in most Ghanaian water bodies is the result of improper management of water used by industries. In the same vein, Croitoru et al. (2019) revealed in their report to the World Bank how industrial activities had degraded the quality and

quantity of water resources along the coast of Benin, Cote D'ivoire, Senegal, and Togo in West Africa.

Furthermore, the influence of LIT on WUE was statistically immaterial in the main and LI panels. This signposts that the literacy rate of individuals in West Africa did not have many reflections on their efficient use of water resources. On the other hand, LIT surged WUE in the LMI panel. This implies that the educated people who also have some experience levels are often conscious about the need for environmental protection. Again, educated people can read any information on print and electronic media concerning measures to manage the available water resources sustainably. For this reason, economies and institutions that provide citizens with the appropriate information required to promote water use efficiency should present them with requisite resources to ensure sustainable water for all. Palpably, an increase in literacy rate has been documented as a critical indicator for environmental sustainability. Where frequent training and learning of environmental rules are not practiced, adverse practices like overexploitation and misuse of water other resources are evident (Dauda et al. 2021). This finding in our study is in line with Joshi and Amadi (2013), whose study showed how school children managed the little water provided to them by the school for drinking and handwashing. The result also supports Desha et al. (2015), who reported that educated people often adhere to environmental regulations and protect natural resources. However, the outcome of our study contradicts that of Proudfoot and Kelley (2017), who revealed that technological advancement through an increase in education could harm water use; explaining that through an increase in education, people learn how to manufacture equipment and chemicals which in the long-run, pollute the environment and water resources. However, our result aligns with Ma et al. (2019) that education positively correlates with the efficient use of water resources.

## 5 Conclusion and policy implications

This is the final section of the study. It comprises the conclusion, recommendations for policy implementation based on the results gathered, the limitation for the study, and suggestions for future research on water use efficiency in West Africa and Africa as a whole.

### 5.1 Conclusion

While various governments in Africa strive to ensure economic development, water scarcity has also been one of the challenges they are battling. The reason is that better living conditions coupled with trade openness have led to more people settling in the urban centers and several multinational companies relocating into Africa. However, these entities rely on water resources for survival and production, hence ensuring efficient use of the water resources. This study analyzed the effect of URB and FDI on WUE for eleven (11) countries in West Africa from 2007 to 2016. For critical examination, the countries were categorized into the low-income panel (6 countries), the lower-middle-income panel (5 countries), and the main panel (11 countries). The authors used efficient panel estimation methods to determine the accuracy and reliability of the results. Using the dynamic slacks-based model, the study began with a data envelopment analysis to derive the water use efficiency scores for the various decision-making units. With the econometric approaches, a cross-sectional dependence test was initially performed, and the study's findings revealed no issues of cross-sectional independence.

Afterward, the CIPS and CADF panel unit root tests were performed to check the stationarity of the panel series, and the outcome showed that all the panel series were nonstationary at levels but assumed stationarity at first difference. The CCEMG estimator was then employed to analyze the long-run effect of urbanization and foreign direct investment and the adopted control variables on water use efficiency. Finally, the DCCEMG estimator was used as a robust checker for the CCEMG estimation.

Results of the DSBM showed that only five countries reached the efficiency frontier of 1.00. This outcome is not startling because although Africa is one of the water-scarce continents, water use efficiency has been a gray area for research and policy implementation. This outcome is also evidence that water use efficiency in West Africa is determined by certain factors that require investigation. The results further showed that countries in the low-income group performed better than countries in the lower-middle group when the sampled countries were classified into income levels. The reason may be that the low-income countries do not depend much on water resources, hence the less pressure on the resource. It could also be that those countries within the LMI panel do not have enough water-saving technologies and expertise to ensure efficient use of water resources in the municipal, industrial, and agricultural sectors.

Estimates from the CCEMG approach revealed different outcomes regarding the connection amid the long-run equilibrium of the panel series. From the outcome of the study, URB had a substantial positive effect on WUE across all panels. The reason is that as people migrate into the urban centers for employment and a better standard of living, more water is withdrawn to meet their growing demands, which in the long run, impacts the value and volume of the resource. Regarding foreign direct investment, a positive and statistically significant impact on WUE was exhibited in the main panel, but a negative influence was found in the LMI panel, whereas an insignificant positive impact was established in the LI panel. The outcome for the whole panel could be that on average multinational companies in West Africa adhere to environmental regulations in the host countries in light of global water scarcity. On the contrary, the negative influence found in the LMI panel could be that multinational companies within these countries do not have adequate and innovative technologies for managing the quality and quantity of water withdrawn for their respective production purposes. Markedly, export had a little influence on WUE across panels which implies that most of the exported products from West Africa do not require much water for production. Of interest to the authors, IND exhibited an insignificant positive impact on WUE in the main panel, but a significant and negative influence of IND on WUE was found in the LMI and LI panels. A possible implication aligned to this outcome could be that the authorities responsible for water resources management do not check the rate of abstraction, equipment, and how water–water from the industries are treated before it is finally disposed into nearby waterbodies. Industries in the LMI and LI countries that do not invest in research and development to acquire novel expertise on mechanisms to use water efficiently and outmoded and water-intensive equipment may also contribute to poor water use efficiency. Finally, LIT enhanced WUE in the LMI panel. This signposts that people who are educated are conscious of protecting their environment, including water management. In addition, since they can read, it is easy for authorities in charge of water resources management to create awareness on the state of water resources and the need to promote the efficient use of the resource. Also, statistically significant and positive feedbacks from URB and FDI to WUE were established in the main panel for the CCEMG, and DCCEMG approaches after controlling EX, IND, and LIT. Notably, the checks for robustness through the DCCEMG approach showed consistency in the



results, indicating that policymakers can consider the outcomes of this study because of the robustness of the estimator.

## 5.2 Policy recommendations

First, authorities in Benin, Burkina Faso, Liberia, Mauritania, and Togo who are responsible for water resources management should strengthen their policies and initiatives to promote efficient use of water resources. This will aid in ensuring sustainable, adequate, and quality water supply and reduce water stress and its associated repercussion on both humans and the ecosystem. For the countries (Cote d'Ivoire, Ghana, Mali, Nigeria, Niger, and Sierra Leone) that recorded efficiency scores below the threshold of 1.00, this study recommends the adoption of innovative technologies that promote water use efficiency since high levels of water withdrawals in those countries could have an ultimately negative impact on the available water resources.

From the study, URB increases water use efficiency in the sampled WA countries. Therefore, the responsible authorities should continue with the measures that they have adopted. Also, the authorities responsible for water resources management should formulate and implement other policies that would promote the sustainable and efficient use of water resources. This can be done through the promotion of rainwater harvesting and wise use of the water resource. For instance, there could be a policy that residents who use water below a certain threshold will enjoy some benefits while those who exceed the threshold will pay more. This will eventually motivate more people not to exceed their limit of water withdrawal. Also, recycled water can be channeled into industrial and irrigation purposes while the abstracted freshwater is used for drinking or other critical tenacities.

Since FDI had positive feedback on WUE in WA, authorities in the WA countries are encouraged to open up for more investors because their knowledge and technological spillover will help protect the available water resources via using them efficiently. Nonetheless, the authorities should also enforce the pay-as-you-pollute policy and penalize any organization that defies the recommended water demand management plans. Moreover, leaders in WA countries should reach out to foreign companies with water and environmentally friendly production methods whose ideas and technologies are adopted in the other sectors of the economy. The host economies should also learn from a country like China with relatively strong supervision over foreign capital regarding the water environment and has reported good water use efficiency from enterprises invested by foreign capital. This will aid in improving their adoption capacity, in the long run, allowing for more effective and fruitful technological and information spillover.

As EX and IND harmed WUE in WA, this research suggests that authorities should frequently monitor the amount of water withdrawn for industrial purposes at a particular period and periodically monitor how wastewater from those sites is treated before discharging into nearby water bodies or the environment. Also, the authorities should liaise with firm owners and educate them on the advantage of linking water use efficiency to the firms' outputs. That is, the ability to use water efficiently in their production will increase their output and, at the same time, ensure a sustainable water supply. Furthermore, authorities should ensure that the production and exportation of water-intensive products are minimized. This can be replaced with goods that require less water for production to reduce exploitation of the available water resources.

Furthermore, the study recommends that the literacy rate of citizens, especially in the LI countries in WA, should be enhanced since it can promote sustainable water use

efficiency. This can be done by ensuring that at least every child has basic education. This is because when the children can read and write, they will transfer the knowledge acquired from schools in their daily dealings. The children would be able to manage and protect resources, including water that is available to them. They would as well become agents of transformation in building the capacity of their fellow friends and family. Also, authorities in the various WA countries should include natural resources management, especially water resources management, in their respective constitution as a civil responsibility.

Finally, authorities should consider the liaison amid URB, FDI, and WUE in the formulation and implementation of water policies in WA. For instance, countries (Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali, and Togo) within the Volta Basin should harness policies such as wastewater treatment and riparian buffer zone. This will promote sustainable water resources management such as controlling water pollution from upstream countries (Burkina Faso and Mali). More importantly, authorities in the WA countries should engage in renewable energy for electric power such as solar and wind instead of hydroelectricity to reduce the huge volumes of water required to generate electricity.

### 5.3 Future research direction

The authors wanted to include sewage as an undesired output and water price as the desired output in evaluating water use efficiency in SSA. However, adequate data on sewage and water price were not achieved at the time of the study. Therefore, future research should consider the amount of sewage released and water price in the context of SSA economies because they may have a crucial impact on the quality and efficient use of water resources.

**Funding** The financial assistance was provided by the National Natural Science Foundation of China (71704066; 71704068; 71804042); National Key Research and Development Project of China (2017YFC0404600); and the China Postdoctoral Science Foundation (2017M621621).

**Data availability** Data about the study variables can be obtained from <https://databank.worldbank.org/source/world-developmentindicators> and <http://www.fao.org/nr/water/aquastat/data/query/index>.

## Declarations

**Conflict of interests** The authors declare that they have no conflict of interest.

**Consent to publish** The authors of this manuscript grant the publisher of this journal the sole exclusive license of the full copyright, which licenses the Publisher hereby accept.

**Disclaimer** Any opinions, findings, and conclusions, or recommendations expressed in this paper are those of authors and do not necessarily reflect the views of the funding body.

## References

- Abubakar, I. R. (2018). Strategies for coping with inadequate domestic water supply in Abuja Nigeria. *Water International*, 43(5), 570–590. <https://doi.org/10.1080/02508060.2018.1490862>
- Addae, E. A., & Amowini, N. (2020). Assessment of water use efficiency in sub-Sahara Africa: Application of the Malmquist productivity index. *International Journal of Scientific Research in Science and Technology*, 7, 66–78. <https://doi.org/10.32628/IJSRST20766>
- African Ministers' Council on Water. <http://www.amcow-online.org>. Downloaded on 8th August 2021.

- Akhmouch, A., Clavreul, D., & Glas, P. (2018). Introducing the OECD principles on water governance. *Water International*, 43, 5–12. <https://doi.org/10.1080/02508060.2017.1407561>
- Akpan, V. E., & Olukanni, D. O. (2020). Hazardous waste management: An African overview. *Recycling*, 5(3), 15. <https://doi.org/10.3390/recycling5030015>
- Aust, V., Morais, A. I., & Pinto, I. (2019). How does foreign direct investment contribute to sustainable development goals? Evidence from African countries. *Journal of Cleaner Production*. <https://doi.org/10.1016/j.jclepro.2019.118823>
- Awolusi, O. D., Adeyeye, O. P., & Pelser, T. G. (2017). Foreign direct investment and economic growth in Africa: A comparative analysis foreign direct investment and economic growth in Africa: A comparative analysis. *Int J Sus Econs*, 9, 183–198. <https://doi.org/10.1504/IJSE.2017.085062>
- Balha, A., Vishwakarma, B. D., Pandey, S., & Singh, C. K. (2020). Predicting the impact of urbanization on water resources in megacity Delhi. *Remote Sensing Applications: Soc Environ*, 20, 100361. <https://doi.org/10.1016/j.rsase.2020.100361>
- Baloch, M. A., Ozturk, I., Bekun, F. V., & Khan, D. (2021). Modeling the dynamic linkage between financial development, energy innovation, and environmental quality: Does globalization matter? *Business Strategy and the Environment*, 30, 176–184.
- Bao, C., & Chen, X. (2017). Spatial econometric analysis on influencing factors of water consumption efficiency in urbanizing China. *Journal of Geographical Sciences*, 27(12), 1450–1460.
- Bigelow, D. P., Plantinga, A. J., Lewis, D. J., & Langpap, C. (2017). How does urbanization affect water withdrawals? Insights from an econometric-based landscape simulation. *Land Econs*, 93, 413–436.
- Boretti, A., & Rosa, L. (2019). Reassessing the projections of the world water development report. *Npj Clean Water*, 2, 1–16. <https://doi.org/10.1038/s41545-019-0039-9>
- Bretteny, W., & Sharp, G. (2016). Efficiency evaluation of urban and rural municipal water service authorities in South Africa: A data envelopment analysis approach. *Water SA*, 42, 11–19.
- Cai, J., Yin, H., & Varis, O. (2018). Impacts of urbanization on water use and energy-related CO2 emissions of residential consumption in China: A Spatio-temporal analysis during 2003–2012. *Journal of Cleaner Production*, 194, 23–33. <https://doi.org/10.1016/j.jclepro.2018.05.117>
- Cerqueira, T. C., Mendonça, R. L., Gomes, R. L., de Jesus, R. M., & da Silva, D. M. L. (2020). Effects of urbanization on water quality in a watershed in northeastern Brazil. *Environmental Monitoring and Assessment*, 192, 1–17.
- Chudik, A., & Pesaran, M. H. (2015). Common correlated effects estimation of heterogeneous dynamic panel data models with weak exogenous regressors. *J Econ*, 188, 393–429.
- Cosgrove, W. J., & Loucks, D. P. (2015). Water management: Current research, and future challenges and directions. *Water Resources Research*, 51, 4823–4839. <https://doi.org/10.1002/2014WR016869>
- Croitoru, L., Miranda, J. J., & Sarraf, M. (2019). *The Cost of coastal zone degradation in West Africa* (p. 20433). World Bank.
- Dauda, L., Long, X., Mensah, C. N., Salman, M., Boamah, K. B., Ampon-Wireko, S., & Dogbe, C. S. K. (2021). Innovation, trade openness and CO2 emissions in selected countries in Africa. *Journal of Cleaner Production*, 281, 125143.
- De Haan, K. (2020). Progressing towards understanding water use efficiency in Southern, Ontario Canada: Quantifying water use efficiency metrics (WUE) and investigating soil and plant physiology influences on WUE. Master's thesis, University of Waterloo.
- Deng, X., Zhang, F., Wang, Z., Li, X., & Zhang, T. (2015). An extended input-output table compiled for analyzing water demand and consumption at county level in China. *Sustainability*, 6, 3301–3320. <https://doi.org/10.3390/su6063301>
- Desha, C., Robinson, D., & Sproul, A. (2015). Working in partnership to develop engineering capability in energy efficiency. *Journal of Cleaner Production*, 106, 283–291.
- Dieter, C. A. (2018). *Water availability and use science program: Estimated use of water in the United States in 2015*. Geological Survey.
- Ding, X., Tang, N., & He, J. (2019). The threshold effect of environmental regulation, FDI agglomeration, and water utilization efficiency under double control actions—an empirical test based on yangtze river economic belt. *Water*, 11, 1–13. <https://doi.org/10.3390/w11030452>
- Donnelly, K., & Cooley, H. (2015). *Water use trends in the United States*. A report by the Pacific Institute, California. <http://pacinst.org/publication/water-use-trends-in-the-united-states>.
- Duncan, A. E. (2020). The dangerous couple: Illegal mining and water pollution—A case study in Fena river in the Ashanti Region of Ghana. *Journal of Chemistry*, 2020, 1–9. <https://doi.org/10.1155/2020/2378560>
- Ellis, M., Dillich, S., & Margolis, N. (2009). *Industrial water use and its energy implications, prepared by energetics incorporated for the US Department of Energy, Office of Energy Efficiency and Renewable Energy, and Office of Industrial Technologies*.

- Fang J. (2010). The impacts of climate change on water resources and agriculture in China. *Nature*, 467, 43–51. <https://doi.org/10.1038/nature09364>
- FAO. (2017a). *Does improved irrigation technology save water? A review of the evidence*. Regional initiative on water scarcity for the Near East and North Africa. Cairo, Egypt.
- FAO. (2017b). *Water for sustainable food and agriculture*. A report produced for the G20 Presidency of Germany. <http://www.fao.org/3/a-i7959e.pdf>.
- Färe, R., & Grosskopf, S. (1997). Intertemporal production frontiers: With dynamic DEA. *J Ope Res Soc*, 48, 656–656.
- Fayiga, A. O., Ipinmoroti, M. O., & Chirenje, T. (2018). Environmental pollution in Africa. *Environ Dev Sustain*, 20(1), 41–73. <https://doi.org/10.1007/s10668-016-9894-4>
- Feng, L., Chen, B., Hayat, T., Alsaedi, A., & Ahmad, B. (2017). The driving force of water footprint under the rapid urbanization process: A structural decomposition analysis for Zhangye city in China. *Journal of Cleaner Production*, 163, S322–S328.
- Ferro, G., Lentini, E. J., Mercurio, A. C., & Romero, C. A. (2014). Efficiency in Brazil's water and sanitation sector and its relationship with regional provision, property and the independence of operators. *Utilities Policy*, 28, 42–51. <https://doi.org/10.1016/j.jup.2013.12.001>
- Fishman, R., Devineni, N., & Raman, S. (2015). Can improved agricultural water use efficiency save India's groundwater? *Environmental Research Letters*, 10, 084022.
- Flörke, M., Schneider, C., & McDonald, R. I. (2018). Water competition between cities and agriculture driven by climate change and urban growth. *Nature Sustainability*, 1, 51–58.
- Gidion, D. K., Hong, J., Hou, B., Shillamkwese, S. S., Adams, M. Z., & Khoveyni, M. (2019). Consistency in efficiency benchmarking: Urban water utility regulation with performance improvement. *Water Supply*, 19, 1955–1964.
- Global water partnership (GWP). (2017). *Annual report*. Stockholm, Sweden. Downloaded on 2/08/2021 from <https://www.gwp.org/globalassets/global/about-gwp/publications/annual-reports/gwp-annual-report-2017.pdf>.
- Guo, J., Xu, Y., & Pu, Z. (2016). Urbanization and its effects on industrial pollutant emissions: An empirical study of a Chinese case with the spatial panel model. *Sustainability*, 8, 1–15. <https://doi.org/10.3390/su8080812>
- Hayford, P. (2018). Evaluating water-use efficiency in Sorghum-pigeonpea (*Sorghum bicolor L. Moench-cajanus Cajan [L] Millsp.*) Diversified cropping systems in marginal areas of Ghana and Mali (Doctoral dissertation, Michigan State University).
- Hsieh, J. C., Ma, L. H., & Chiu, Y. H. (2019). Assessing China's Use Efficiency of Water Resources from the Resampling Super Data Envelopment Analysis Approach. *Water*, 11(5), 1069.
- Jain, R., & Chetty, P. (2019). Empirical evidence shows the impact of FDI on water pollution. Project Guru. Available at: <https://www.projectguru.in/empirical-evidence-shows-the-impact-of-fdi-on-water-pollution> [Accessed 04 Sep. 2020].
- Jiang, L., Deng, X., & Seto, K. C. (2013). The impact of urban expansion on agricultural land-use intensity in China. *Land Use Policy*, 35, 33–39.
- Joshi, A., & Amadi, C. (2013). Impact of water, sanitation, and hygiene interventions on improving health outcomes among school children. *Journal of Environment Public Health*, 2013, 1–10. <https://doi.org/10.1155/2013/984626>
- Joshua, U., & Bekun, F. V. (2020). The path to achieving environmental sustainability in South Africa: The role of coal consumption, economic expansion, pollutant emission, and total natural resources rent. *Environmental Science and Pollution Research*, 27(9), 9435–9443.
- Jun, W., Zakaria, M., Shahzad, S. J. H., & Mahmood, H. (2018). Effect of FDI on pollution in China: New insights based on wavelet approach. *Sustainability*, 10(11), 3859. <https://doi.org/10.3390/su10113859>
- Kagohashi, K., Tsurumi, T., & Managi, S. (2015). The effects of international trade on water use. *PloS one*, 10(7), e0132133. <https://doi.org/10.1371/2Fjournal.pone.0132133>
- Kobzev Kotásková, S., Procházková, P., Smutka, L., Maitah, M., Kuzmenko, E., Kopecká, M., & Höning, V. (2018). The impact of education on economic growth: The case of India. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 66, 253–262. <https://doi.org/10.11118/actaun201866010253>
- Kock, N., & Lynn, GS. (2012). Lateral collinearity and misleading results in variance-based SEM: An illustration and recommendations. *Journal of the Association for Information Systems*, 13(7) Available at SSRN: <https://ssrn.com/abstract=2152644>
- Koech, R., & Langat, P. (2018). Improving irrigation water use efficiency: A review of advances, challenges and opportunities in the Australian context. *Water*, 10(12), 1771. <https://doi.org/10.3390/w10121771>

- Luo, Y., Yin, L., Qin, Y., Wang, Z., & Gong, Y. (2018). Evaluating water use efficiency in China's Western Provinces based on a slacks-based measure (SBM)-undesirable window model and a Malmquist productivity index. *Symmetry*, *10*, 1–13. <https://doi.org/10.3390/sym10080301>
- Ma, H., Shi, C., & Chou, N. T. (2016). China's water utilization efficiency: An analysis with environmental considerations. *Sustainability*, *8*(6), 516. <https://doi.org/10.3390/su8060516>
- Ma, S., Dai, J., & Wen, H. (2019). The influence of trade openness on the level of human capital in China: On the basis of environmental regulation. *Journal of Cleaner Production*, *225*, 340–349.
- Ma, T., Sun, S., Fu, G., Hall, J. W., Ni, Y., He, L., & Zhou, C. (2020). Pollution exacerbates China's water scarcity and its regional inequality. *Nature Coms*, *11*(1), 1–9. <https://doi.org/10.1080/20964129.2020.1779010>
- Matveeva, L. G., Chernova, O. A., Kosolapova, N. A., & Kosolapov, A. E. (2018). Assessment of water resources use efficiency based on the Russian Federation's gross regional product water intensity indicator. *Regional Statistics*, *8*(2), 154–169. <https://doi.org/10.15196/RS080201>
- McGrane, S. J. (2016). Impacts of urbanization on hydrological and water quality dynamics, and urban water management: a review. *Hydro Sci J*, *61*, 2295–2311. <https://doi.org/10.1126/sciadv.1500323>
- Mensah, I. A., Sun, M., Gao, C., Omari-Sasu, A. Y., Zhu, D., Ampimah, B. C., & Quarcoo, A. (2019). Analysis on the nexus of economic growth, fossil fuel energy consumption, CO2 emissions, and oil price in Africa based on a PMG panel ARDL approach. *Journal of Cleaner Production*, *228*, 161–174. <https://doi.org/10.1016/j.jclepro.2019.04.281>
- Moglia, M. (2014). Urban agriculture and related water supply: Explorations and discussion. *Hab Int*, *42*, 273–280. <https://doi.org/10.1016/j.habitatint.2014.01.008>
- Musah, M., Kong, Y., Mensah, I. A., Antwi, S. K., & Donkor, M. (2020). The link between carbon emissions, renewable energy consumption, and economic growth: A heterogeneous panel evidence from West Africa. *Environ Sci Pol Res*, *27*, 28867–28889.
- Nafchi, R. A. (2016). Comparison of water use efficiency in Alfalfa using water and waste water. *Journal of Agricultural Chemistry and Environment*, *5*, 191–199. <https://doi.org/10.4236/jacen.2016.54020>
- Naroua, I., Sinobas, L. R., & Calvo, R. S. (2014a). Water use efficiency and water productivity in the Spanish irrigation district "Río Adaja." *International Journal of Agricultural Policy and Research*, *2*(12), 484–491.
- Naroua, I., Sinobas, L. R., & Calvo, R. S. (2014). Water use efficiency and water productivity in the Spanish irrigation district "Río Adaja." *International Journal of Agricultural Policy and Research*, *2*, 484–491.
- Ngene, B. U., Nwafor, C. O., Bamigboye, G. O., Ogbiye, A. S., Ogundare, J. O., & Akpan, V. E. (2021). Assessment of water resources development and exploitation in Nigeria: A review of integrated water resources management approach. *Heliyon*, *7*(1), e05955.
- Ngoran, S. D., Xue, X. Z., & Wesseh, P. K., Jr. (2016). Signatures of water resources consumption on sustainable economic growth in Sub-Saharan African countries. *International Journal of Sustainable Built Environment*, *5*, 114–122. <https://doi.org/10.1016/j.ijsbe.2016.04.002>
- Nicholson, S. E., Funk, C., & Fink, A. H. (2018). Rainfall over the African continent from the 19th through the 21st century. *Global and planetary change*, *165*, 114–127. <https://doi.org/10.1016/j.gloplacha.2017.12.014>
- Okafor, G. (2015). Locational determinants of US outward FDI into Sub-Saharan Africa. *The Journal of Developing Areas*, *49*, 187–205.
- Pesaran, M. H. (2004). General diagnostic test for cross-section dependence in panels. Cambridge Working Papers in Economics 1240
- Pesaran, M. H. (2006). Estimation and inference in large heterogeneous panels with multifactor error structure. *Econometrica*, *74*, 967–1012.
- Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*, 265–312. <https://doi.org/10.1002/jae.951>
- Piao, S., Ciais, P., Huang, Y., Shen, Z., Peng, S., Li, J., & Fang, J. (2010). The impacts of climate change on water resources and agriculture in China. *Nature*, *467*, 43–51. <https://doi.org/10.1038/nature09364>
- Proudfoot, R., & Kelley, S. (2017). Can technology save the planet? WWF Australia <https://www.wwf.org.au/ArticleDocuments/360/pub-can-technology-save-the-planet-30may17.pdf.aspx?Embed=Y>.
- Rashid, H., Manzoor, M. M., & Mukhtar, S. (2018). Urbanization and its effects on water resources: An exploratory analysis. *Asian J Water, Environ Pol*, *15*, 67–74.
- Ren, C., Li, R., & Guo, P. (2016). Two-stage DEA analysis of water resource use efficiency. *Sustainability*, *9*(1), 52. <https://doi.org/10.3390/su9010052>
- Rustam, A., Wang, Y., & Zameer, H. (2020). Environmental awareness, firm sustainability exposure and green consumption behaviors. *Journal of Cleaner Production*, *268*, 122016.

- Shahani, W. A., Kaiwen, F., & Memon, A. (2016). Impact of laser levelling technology on water use efficiency and crop productivity in the cotton-wheat cropping system in Sindh. *International Journal of Research Granthaalayah*, 4, 220–231.
- Shang, Y., Zhai, J., Shi, Z. Y., & Sang, X. (2016). Influencing factor identification of industrial water use changes in Tianjin and their impact assessment. *Energy Procedia*, 88, 58–62. <https://doi.org/10.1016/j.egypro.2016.06.017>
- Sharma, S. (2017). Effects of urbanization on water resources: Facts and figures. *International Journal of Scientific and Engineering Research*, 8, 433–459.
- Shi, Q., Chen, S., Shi, C., Wang, Z., & Deng, X. (2015). The impact of industrial transformation on water use efficiency in northwest region of China. *Sustainability*, 7(1), 56–74.
- Sinha, A., & Shahbaz, M. (2018). Estimation of environmental Kuznets curve for CO2 emission: Role of renewable energy generation in India. *Ren Energy*, 119, 703–711.
- Sun, D., Addae, E. A., Jemmali, H., Mensah, I. A., Musah, M., Mensah, C. N., & Appiah-Twum, F. (2021). Examining the determinants of water resources availability in sub-Sahara Africa: A panel-based econometrics analysis. *Environmental Science and Pollution Research*. <https://doi.org/10.1007/s11356-020-12256-z>
- Tone, K. (2011). Slacks-based measure of efficiency. In W. W. Cooper & L. M. Seiford (Eds.), *Handbook on data envelopment analysis* (2nd ed., Vol. 675, pp. 195–209). Springer.
- Tone, K., & Tsutsui, M. (2010). Dynamic DEA: A slacks-based measure approach. *Omega*, 38, 145–156.
- Vos, J., & Boelens, R. (2016). The Politics and consequences of virtual water Export. In P. Jackson, W. Spiess, & F. Sultana (Eds.), *Eating, drinking: surviving springer briefs in global understanding*. Springer. [https://doi.org/10.1007/978-3-319-42468-2\\_4](https://doi.org/10.1007/978-3-319-42468-2_4)
- Wang, S., Zhou, L., Wang, H., & Li, X. (2018). Water use efficiency and its influencing factors in China: Based on the data envelopment analysis (DEA)-Tobit model. *Water*, 10, 1–16.
- Wang, W., Gao, L., Liu, P., & Hailu, A. (2014). Relationships between regional economic sectors and water use in a water-scarce area in China: A quantitative analysis. *J Hydro*, 515, 180–190.
- Ward, C., Torquebiau, R., & Xie, H. (2016). Improved agricultural water management for Africa's drylands. *World Bank Publications*. <https://doi.org/10.1596/978-1-4648-0832-6>
- WDI. (2019). World Development Indicators (Data Bank).
- Westfall, P. H. (2014). Kurtosis as peakedness 1905–2014 RIP. *The American Statistician*, 68(3), 191–195.
- World Bank. (2013). Enterprise Surveys. <http://www.enterprisesurveys.org>.
- World Water Assessment Programme (WWAP). (2015). *The United Nations world water development report 2015: Water for a Sustainable World*. Paris UNESCO.
- Xu, R., Wu, Y., Wang, G., Zhang, X., Wu, W., & Xu, Z. (2019). Evaluation of industrial water use efficiency considering pollutant discharge in China. *PLoS One*, 14(8), e0221363. <https://doi.org/10.1371/journal.pone.0221363>
- Yasmeen, H., Tan, Q., Zameer, H., Tan, J., & Nawaz, K. (2020). Exploring the impact of technological innovation, environmental regulations, and urbanization on ecological efficiency of China in the context of COP21. *Journal of Environmental Management*, 274, 111210. <https://doi.org/10.1016/j.jenvman.2020.111210>
- Yeleliere, E., Cobbina, S. J., & Duwieujuah, A. B. (2018). Review of Ghana's water resources: The quality and management with a particular focus on freshwater resources. *Applied Water Science*, 8, 93. <https://doi.org/10.1007/s13201-018-0736-4>
- Zaidi, S. A. H., Zafar, M. W., Shahbaz, M., & Hou, F. (2019). Dynamic linkages between globalization, financial development, and carbon emissions: Evidence from Asia Pacific Economic Cooperation countries. *Journal of Cleaner Production*, 228, 533–543.
- Zameer, H., Yasmeen, H., Wang, R., Tao, J., & Malik, M. N. (2020). An empirical investigation of the coordinated development of natural resources, financial development and ecological efficiency in China. *Resources Policy*, 65, 101580.
- Zhang, J., Qu, Y., Zhang, Y., Li, X., & Miao, X. (2019). Effects of FDI on the efficiency of government expenditure on environmental protection under fiscal decentralization: A spatial econometric analysis for China. *International Journal of Environment Research Public Health*, 16(14), 2496. <https://doi.org/10.3390/ijerph16142496>
- Zhang, R., Lu, C. C., Lee, J. H., Feng, Y., & Chiu, Y. H. (2019a). Dynamic environmental efficiency assessment of industrial water pollution. *Sustainability*, 11(11), 3053. <https://doi.org/10.3390/su11113053>
- Zheng, J., Zhang, H., & Xing, Z. (2018). Re-examining regional total-factor water efficiency and its determinants in China: A parametric distance function approach. *Water*, 10(10), 1286.
- Zomorrod, A., & Zhou, X. (2017). Impact of FDI on environmental quality of China. *Int J Bus Econs Manage*, 4, 1–15. <https://doi.org/10.18488/journal.62/2017.4.1/62.1.1.15>

- Zongo, B., Zongo, F., Toguyeni, A., & Boussim, J. I. (2017). Water quality in forest and village ponds in Burkina Faso (western Africa). *Journal of Forestry Research*, 28(5), 1039–1048. <https://doi.org/10.1007/s11676-017-0369-8>
- Zurr, A. F., Ieno, E. N., & Elphick, C. S. (2010). A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution*, 1, 3–14.

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

## Authors and Affiliations

Ethel Ansaah Addae<sup>1</sup>  · Dongying Sun<sup>1</sup> · Olivier Joseph Abban<sup>2</sup>

Dongying Sun  
henansdy@jsu.edu.cn

Olivier Joseph Abban  
olivierjosephs@yahoo.com

<sup>1</sup> School of Management, Jiangsu University, Zhenjiang 212013, People's Republic of China

<sup>2</sup> Department of Statistics, School of Finance and Economics, Jiangsu University, Zhenjiang 212013, People's Republic of China