



# Examining the determinants of water resources availability in sub-Saharan Africa: a panel-based econometrics analysis

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## Abstract

With the rapid development of economies, the problem of water resources availability particularly in sub-Saharan Africa (SSA) has increased significantly. Specifically, in recent times, addressing the challenge of access to water resources has become a global issue of which countries in SSA are not exceptional since the adequate supply of potable water is as relevant as economic development. Consequently, this current paper seeks to estimate the determinants of water resources availability in sub-Saharan Africa. For this purpose, a panel-based regression model, which represents the availability of water resources, is specified based on the period 2000 to 2016 to examine a panel of 41 SSA countries sub-sectioned into low, lower-middle, and upper-middle-income nations. Considering the existence of residual cross-sectional reliance, outcomes based on the CIP and CADF unit root tests showed that the variables were not integrated at the same order. This thus leads to the employment of the PMG/ARDL estimation approach which unveiled that (i) agriculture production has a significant negative influence on H<sub>2</sub>O in the lower-middle and low-income panel of SSA countries whereas in the upper-middle-income panel, an insignificant impact is witnessed; (ii) CO<sub>2</sub> emissions affect H<sub>2</sub>O palpably in the upper-middle-income SSA panel while for lower-middle and low-income panels, an adverse effect is identified; (iii) economic growth adversely influenced H<sub>2</sub>O resources in the lower-middle-income panel whereas in the case of the low-income panel, a significant positive liaison is evidenced; (iv) excluding low-income panel, industrial development concerning H<sub>2</sub>O has a significant negative influence in upper-middle and lower-middle-income panels; (v) urbanization homogeneously showed a positive relationship with H<sub>2</sub>O resources across all panels. The results are reconfirmed by the CCEPMG/CS-ARDL and MG employed as robust methods. Causality checks by Dumitrescu-Hurlin test finally revealed a mixture of results regarding the causal paths amid variables among the country panels. Policy recommendations have therefore been proposed based on the study findings.

**Keywords** Water resources availability · Urbanization · Agricultural production · Industrial development · CO<sub>2</sub> emission · Sub-Saharan Africa

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## Introduction

In recent times, addressing the challenge of access to water resources has become a global concern since the adequate supply of potable water is as relevant as the economic development of every country. According to WHO/UNICEF (2015) report, 344 million out of the estimated 768 million people (globally) without access to improved drinking water live in Africa. This, therefore, infers that the sub-Saharan Africa (SSA) region and Africa as a whole have lagged behind other regions in the world in terms of access to water. One interesting historical trend of access to water resources in SSA is that, in 1990, the water supply was 49% which increased to 60% in 2008, and by 2015, the percentage has risen to sixty-eight

(United Nations 2017). Nonetheless, SSA could not meet the Millennium Development Goal (MDG) 7 of halving the share of the population with access to safe drinking water and sanitation. Specifically, it is projected that by 2025, about 25 countries in SSA will be facing water shortage; meaning approximately 230 million people will be living in water scarce areas (< 1000 cubic meters/capita/year) while another 480 million inhabitants will be in water-stressed areas (1000–1700 cubic meters/capita/year).

Thus, about the issue of water scarcity, urbanization has been identified as one of the factors that influence water resource availability. For instance, SSA has been regarded as the fastest urbanizing region currently with about 472 million people and is projected to double in the next 25 years (Saghir and Santoro 2018). Also, the percentage of the urban population in SSA was 14.7 in 1960, but this rose to about 40.2 in 2018 (WDI 2019). Linking urbanization with water resources, UN Water (2019) has reported that the development of every nation depends on the available water resources because the various sectors require water in their production processes. Again, while a junk of the rural population migrates into the urban centers for greener pastures, heavy pressures are placed on the municipal facilities as well as water supply. This is illustrated in the urban environmental transition theory (McGranahan et al. 2001) that, as cities develop, their environmental impact move from local, immediate, and health-threatening to globalized, delayed, and ecosystem threatening such as water pollution. Also, in the quest to feed the growing population, agricultural practices are intensified, and this requires much water use. It is estimated in FAO (2017) report that about 69% of water is withdrawn for agriculture, 23% for industrial, and 8% for domestic use. Solarin (2017) further added that industrial growth as a result of urbanization leads to a greater dependence on water resources. Besides, the growing risk of CO<sub>2</sub> emissions due to ongoing economic development has led to climate change, which put severe threats on water resources globally, including SSA (Urama and Ozor 2010). According to WDI (2019), 126,087 kilotons of CO<sub>2</sub> emissions in SSA was recorded in 1960, but this figure increased to 822,819 kilotons in 2014 which is about 6.5% increase. These statistics confirm World Bank (2013) report on climate extremes, regional impacts, and the case for resilience that with the 2 °C warming, the rates of recharge of water resources in some parts of Southern Africa will decrease by 50–70% whereas there will be an increase in the rates of recharge of water resources in some parts of Eastern Africa.

The integrated water resource management aims to secure enough quality water for the people. Thus, the MDG 7 was to half the proportion of population lacking water and sanitation by 2015, ensure enough water for food production, and increase the recycling and reuse of wastewater to supplement new resource development, protect the vital ecosystem, and

reduce the crisis of water governance (GWP 2018). By this, governments plan their water policies, water demand management plans, and other regulations to manage the use and protection of water resources (FAO 2011; UN 2015). Interestingly, water scarcity is still on the increase (Burek et al. 2016), and most countries in SSA are experiencing this insufficiency (GIZ 2019). It is against this background that this current research seeks to examine how certain socio-economic and environmental factors have influenced water resources in SSA over time. Notably, studies on estimating the determinants of water resource availability have important guiding significance for the formulation of regional development policies concerning water resource management. Thus, considering the short-comings of other researches in SSA about water resource availability determinants, this recent study using a panel data model within a multi-sectoral framework contributes to the literature in the following ways

1. In light of the increasing global water scarcity and its associated effect on humans and the ecosystem, numerous studies have largely considered physiological components of water resources such as the pH, color, and turbidity among others. This study, unlike the others, focuses on the impact of socio-economic determinants on water resources within the sub-Sahara region in a multivariate framework by incorporating urbanization, economic growth, emission of CO<sub>2</sub>, agriculture, and industrialization as key determinants.
2. Although a few pieces of research exist on water resources and other variables specifically in SSA, to the best of familiarity, none of them takes into consideration issues of residual cross-sectional correlations and/or heterogeneity. Rather, such studies presume independent residual correlations and/or homogeneity. Notably, relying on the pre-assumptions of cross-sectional independence and homogeneity likely results in inefficient and inaccurate estimation outcomes if the panel data are actually heterogeneous and cross-sectionally dependent. Hence, we examined whether or not the panel data used in this study is homogeneous and cross-sectionally independent, and indeed confirm the issues of cross-sectional dependence and heterogeneity, thus executing panel econometric approaches robust to such issues.
3. Also, to the best of our knowledge, most studies in SSA concerning water resources availability and other factors center on the regional or panel perspective without considering the disparities that might exist between sub-regional classifications. Thus, this current study contributively addresses this issue by categorizing the panel of sampled SSA economies into three (3) different sub-classifications in terms of income levels (upper-middle, lower-middle, and low income) based on the World Bank country and lending group classification in 2018.

Such sub-classifications are framed to examine whether the water resources and its proposed drivers in SSA are influenced by features unique to the aforesaid income classifications.

The remaining sections of the study are organized as follows: “Literature review” provides a literature review; the methodology and data are found in “Methodology”; “Results and discussions” presents the results and discussion; and lastly, the conclusion and recommendation of the study are presented in “Conclusion and policy recommendations.”

## Literature review

In recent years, urban growth, coupled with industrial development and agricultural intensification, has negatively affected the availability of water resources worldwide. Relevant literature is thus reviewed to comprehend the impact that urbanization, agricultural production, industrial development, economic growth, and CO<sub>2</sub> emissions have had on water resources availability in SSA.

### Urbanization and water resources nexus

Migration influences the growth of every economy. In so doing, there is excessive dependence on water resources for municipal, agricultural, and industrial activities (FAO 2017). According to Capps et al. (2016), a considerable number of the rural populace have migrated into the urban centers due to inadequate access to food supplies, protection from conflict resulting from politics or ecological harm, lack of employment opportunities, and a better standard of living including a constant supply of potable drinking water. Industries, on the other hand, spring up to meet the growing demand for goods and services for the increasing urban populace (Guo et al. 2016). These activities exert more pressure on the available water resources by decreasing its quality and quantity (Hu and Cheng 2013). This suggests that urbanization is a significant determinant of stress on water resources.

Nonetheless, to ensure regular access to water supply irrespective of the growing urban population, the theory of sustainable development mandates the creation of policies that include environmental resources such as clean air and water at all levels. This is to ensure the continuous availability of the resources and, at the same time, reduce its pollution (Klarin 2018). Sustainable development goal 6 is thus geared toward ensuring equitable access to quality water resources for all without compromising the future generation (UN 2017). Urbanization may have positively influenced water resources (Ashley et al. 2012; Mcgrane 2015), but Ma et al. (2016), Sharma (2017) and Sabater et al. (2018) have brought to light how urbanization has negatively influenced water resources.

This uncertainty remains an exciting field of research, especially in SSA.

### Economic growth and water resource nexus

Studies have shown that increase in economic growth has a negative influence on water resources (Wang et al. 2018). This is because the various sectors of production depend on water resources to enhance productivity, and this has resulted in researches on water consumption and stress on water resources (Fant et al. 2016; Mekonnen and Hoekstra 2016). The results of these studies have shown that excessive use of water resources does not only reduce the quantity but also pollute the quality. Economic growth is more likely to increase water stress where regulations to protect water resources are not implemented (Gupta et al. 2013), but strict measures and adoption of new technologies will help to reduce water pollution and at the same time increase productivity and economic growth (Akhmouch et al. 2018). Interestingly, there have been varying results on economic growth and water resource nexus. This is because, while scholars like Ngoran et al. (2016) assert that economic growth upsurges stress on water resources, Mcgrane (2015) opposes this notion and states that the development of an economy enhances the state of its water resources. This study will, therefore, find out how economic growth affects water resources in SSA.

### Agricultural production, industrial development, and water resources relationship

In the quest to feed the growing population, agricultural activities are intensified, and this goes hand in hand with water use. For instance, Khatri and Tyagi (2015) stated that several tons of water is required to produce a ton of cereals, and the production of food largely depends on water to the extent that the agricultural sector can consume about 70–90% of freshwater within a region. As more chemicals are used to enhance productivity, some of these chemicals penetrate the soil and the aquifer (Mateo-Sagasta et al. 2017), which pollute the groundwater. Other studies have also shown that wastes from farms usually drain into nearby surface water resources. This does not only degrade the quality and quantity of water resources, but river ecosystems are also affected (Stehle and Schulz 2015). The industrial sector, which depends mainly on raw agricultural products to turn into finished goods to satisfy the demands of the growing population, also consumes many water resources. That is, FAO (2017) report has estimated that globally, the industrial sector consumes about 23% of total water withdrawn. In the context of Africa, Pullanikkatil and Urama (2011) investigated the degree and impacts of water pollution from industries in Lesotho, and the results disclosed that pollutants from industries have a substantial adverse

effect on the convenience of potable water and domestic earnings in the area. In the same vein, a study conducted by Karamage et al. (2016) showed that water resources such as the Kegeza, Akagera, and the Nyabarongo river basins in Rwanda have been recorded to be among water bodies that are extremely polluted in the world due to agricultural production, urbanization, and industrialization. However, it is believed that with adequate technology and human capacity building, pollution of water resources from the agricultural and industrial sectors could be minimized.

### Climate change and water resources availability

The growing risk of CO<sub>2</sub> emissions due to ongoing economic development has led to climate change, which poses severe threats to water resources globally, including SSA (Urama and Ozor 2010). This is because CO<sub>2</sub> emissions released from fossil fuels are assumed to be a key cause of global warming (Mensah et al. 2019a). The increased reliance of industries in SSA on energy from fossil fuel and improper disposal of solid and liquid waste products into water bodies have become a common practice in most SSA countries (Mudhoo et al. 2015). Carbon emissions through an increase in urbanization and economic development have a substantial effect on the environmental equilibrium of the world’s ecosystem in its natural state of which water resources are part (Luo et al. 2019). This current study will thus examine how CO<sub>2</sub> emissions have influenced water resources in SSA over the study period.

Although the population is increasing and civilized modernization is at the peak, water resource availability, access to water resources, and management of water resources are not the same as the former (Boretti and Rosa 2019). However, according to the ecological modernization theory, as cited in Mensah et al. (2019a), issues concerning the environment can develop from one stage to the other. That notwithstanding, there can always be a way to reduce those negative effects when the stakeholders recognize the need for a sustainable environment of which water resources are crucial.

## Methodology

### Empirical model specification

This current study ensues the recent empirical research of Sharma (2017), Wang et al. (2018), Mateo-Sagaster et al. (2017) together with Luo et al. (2019) to estimate the determinants of water resource availability by employing urbanization, gross domestic product, agricultural production, industrial development, and emanation of CO<sub>2</sub> in a multivariate framework. Hence, the proposed water resources availability function which seems to conform to literature is specified as

$$H_2O_{it} = f(URB_{it}, GDPPC_{it}, AGR_{it}, IND_{it}, CO_{2it}) \quad (1)$$

For econometric estimations as well as reducing the issues of potential heteroscedasticity, the variables employed in the study are expressed as linear combinations of their respective parameters and further transformed into natural logarithms respectively. Notably, Ehrlich (1996) reported that variables in their logarithmic transforms provide direct elasticities which facilitate interpretation. Zaidi et al. (2019) as well made it clear that in comparison with a simple linear transformation model, a model in a log-linear framework yields consistent and reliable outcomes empirically. Thus, the improved (augmented) multivariate water resource availability function in a transformed log-linear model based on a panel specification is formulated as

$$\ln H_2O_{it} = \beta_0 + \beta_1 \ln URB_{it} + \beta_2 \ln GDPPC_{it} + \beta_3 \ln AGR_{it} + \beta_4 \ln IND_{it} + \beta_5 \ln CO_{2it} + \varepsilon_{it} \quad (2)$$

Here, H<sub>2</sub>O stands for water resource availability; URB, GDPPC, AGR, IND, and CO<sub>2</sub> are urbanization, gross domestic product per capita, agricultural production, industrial development, and emission of carbon dioxide correspondingly; β<sub>0</sub> is the constant term whereas β<sub>1</sub>, β<sub>2</sub>, β<sub>3</sub>, β<sub>4</sub> and β<sub>5</sub> are slope coefficients measuring the elasticities of water resource availability (H<sub>2</sub>O) with the respect to the afore-stated model regressors; *i* denotes the individual countries within the study panel, and *t* is the study period (2000–2016).

### Reasons for variable selection

Of interest to us, the crises of many governments on the issue of water scarcity are linked to rapid urbanization. That is, thousands of rural people migrate into the urban centers in search of employment while others want to enjoy improved infrastructure in the urban centers. Since water is one of the most important factors for human sustenance, the rising urban population uses water for several domestic purposes. The continuous withdrawal of the water resources coupled with other human activities such as wasting water and dumping of solid waste into nearby urban streams influence the quality and quantity of the water resources. For this reason, when researching on the determinants of water resources availability, the impact of urbanization cannot be overlooked.

Furthermore, to feed the growing urban population, agricultural production has moved from small-scale farming into a large-scale intensification of agricultural mechanization which demands the abstraction of volumes of water to irrigate the farms. Agrochemicals such as fertilizers, pesticides, and weedicides are also applied to the farms to increase the yields. According to Mateo-Segata et al. (2017), improper treatment and management of the agrochemicals drain into nearby water

resources and pollute it. Food and Agricultural Organization (2011) have also reported that agricultural production consumes about 69% of total water resources. Hence, the total effect of agricultural mechanization is equivocal. Besides, SSA has become an industrial hub where many foreign companies are now situated. These industries including mining, agro-processing, and construction use water as one of the main production factors. In countries such as Ghana, Lesotho, Tanzania, and Kenya, mining activities have been recorded by several studies to harm water resources (Yeleliere et al. 2018). That is, water is used in the process of food and beverages, wash minerals, and cool machines. How these industries in SSA countries dispose of wastewater and solid waste remains a topic for discussion. Thus, for developing countries such as those in SSA, we contend that industrial development will harm the water resources.

Last but not the least, every country aims to increase in economic development. Therefore, agricultural production and industrial activities are on the surge in order to accrue more finance for the countries. In the process, more water is required in the various levels of production. Therefore, Ngoran et al. (2016) have stated that the economic growth of SSA countries largely depends on water resources and labor. The aforementioned avowal, therefore, justifies the inclusive economic growth as a potential determinant of water resource availability. Finally, the emission CO<sub>2</sub> has greatly influenced water resources with the reason being that emissions from fossil fuel, coupled with methane and nitrogen that are generated from both plant and animal farms, are key causes of global warming. The study of Mudhoo et al. (2015) thus posits that increased release of fossil fuel which has become a common practice in SSA harms water resources. Considering this assertion, taking the emanation of CO<sub>2</sub> out of the water resource availability model makes the story equivocal concerning investigating the influencers of water resource availability in the SSA region.

### Econometric tests

Before estimating the model as specified in Eq. (2), the panel data is summoned to go through specific stages before achieving the desired objective of the study. Thus, the application of econometric tests proceeds as follows: (i) a cross-sectional reliance test by Pesaran (2004) (Pesaran CD-test) together with Pesaran and Yamagata (2008)'s homogeneity test is employed to verify whether there exist issues of residual cross-sectional dependencies and/or heterogeneity. Mensah et al. (2019b) together with Dong et al. (2018) reported that testing for issues of residual cross-sectional correlations and homogeneity exhibits the importance for the selection of further econometric tests. (ii) Since the period of the panel data employed is fairly large, it is theoretically assumed that study variables will be characterized in a unit root process (Nelson

and Plosser 1982). Based on this assertion and recognizing the potential occurrence of cross-sectional dependence, appropriate panel unit root tests which include the cross-sectionally augmented IPS (CIPS) and cross-sectional augmented Dickey-Fuller (CADF) by Pesaran (2007) are conducted to examine whether the series is stationary. Notably, if the unit root tests show that the data series have no unit root, the method of regression analysis is used in analyzing the characteristics of the series. Nonetheless, if the series has a unit root, then the differenced test is implemented to determine that the series is stationary. Hence, when variables are evidenced to be integrated at the same order, a cointegration test can be carried out. Relying on the aforesaid assertions, this present study proved that our panel data is not long enough to make the unit root effect seeable since not all the series are integrated at the same order (see Table 5) implying that a co-integration relationship is most likely not to be formerly detected. (iii) Accounting for the presence of this aforementioned issue, the study further employed the PMG/ARDL estimator developed by Pesaran et al. (1999) as the main estimation approach to examine affiliations amid the selected variables in the long run. To check the robustness from the PMG/ARDL estimation, the MG estimator of Pesaran and Shin (1995) together with CS-ARDL of CCEPMG estimator by Chudik et al. (2016) is employed. Specifically, though the PMG/ARDL is utilized based on its efficiency regardless of whether the variables are integrated of the same order or not, it has some paleness in the presence of residual cross-sectional correlations. This, therefore, justifies the employment of the CCEPMG/CSARDL as a robust estimator which advantageously handles issues of cross-sectional dependence and heterogeneity.<sup>1</sup> (iv) Finally, a heterogeneous panel Granger causality test of Dumitrescu and Hurlin (2012) which also accounts for residual cross-sectional correlations is utilized to verify the direction of causal affiliations among study variables (Table 9).

### Data source and descriptive statistics summary

This study employed annual panel data for (41) countries in sub-Saharan Africa from 2000 to 2016. The data were generated from the Food and Agricultural Organization (FAO Aquastat 2019) and the World Bank Development Indicators (WDI 2019). Total water withdrawal, agricultural production, CO<sub>2</sub> emission, gross domestic product per capita, industrial development, and urbanization were the variables used in the panel series. According to the World

<sup>1</sup> Though research articles such as that of Asafu-Adjei et al. (2016), Sun et al. (2019), Asteriou et al. (2020) just to mention a few employed the PMG estimator in the presence of cross-sectional dependencies, we addressed this limitation by employing an additional estimator known as the common correlated effect pooled mean group (CCEPMG) using the cross-sectional augmented distributed lag (CS-ARDL) model.

Bank classification, sub-Saharan Africa constitutes forty-eight (48) countries but due to missing data for some countries, only 41 countries with enough data were selected for the period 2000–2016. To establish our study sample, the selected SSA countries were grouped into three sub-panels. That is, upper middle income (UMI, of GNI ranging from \$3996 to \$12,375), lower-middle-income countries (LMI, of GNI ranging from \$1026 to \$3,995), and low-income countries (LI, GNI of \$1025 or less) per the gross national income (GNI) of the World Bank country and lending group classification in 2018 based on the World Bank Atlas procedure. Therefore, our research comprises 5 countries in the UMI panel, 15 countries in the LMI panel, and 21 countries in the LI panel. The countries were grouped into income level sub-panels to investigate how the selected variables (Agricultural production, CO<sub>2</sub> emission, gross domestic product per capita, industrial development, and urbanization) influence water resource availability in the sampled countries to make better policy recommendations pertaining variation in the findings. The study purposely selected SSA because there have been several reports and researches on how socio-economic developments are continuously influencing water resources in SSA. Due to trade openness and foreign direct investments, a lot of foreign companies have emerged in most countries within the SSA region which is perceived to be opportunities for economic growth for the various countries. However, activities such as inadequate disposal of solid and liquid waste, CO<sub>2</sub> emissions, and excessive withdrawal of water have exerted more pressure on the available water resources in SSA. The selected countries from SSA grouped into income levels are outlined in the Appendix as Table 8. Purposely, this study uses agricultural production, CO<sub>2</sub> emission, gross domestic product per capita, industrial development, and urbanization as explanatory variables that are likely to influence water resources based on the reviewed literature (Sharma 2017; Wang et al. 2018; Mateo-Sagasta et al. 2017; Karamage et al. 2016; and Luo et al. 2019). The study considered total renewable water resources per capita (H<sub>2</sub>O) as the dependent variable and it is measured in m<sup>3</sup>/inhab/year. We adopted agriculture value-added current US\$ (AGR) as a measure of agricultural development. Carbon dioxide emissions have led to changes in the climatic conditions altering rainfall patterns; thus, CO<sub>2</sub> measured in kilotons is included in this study. We also measured how economic growth could influence water resources using gross domestic product per capita current US\$ (GDPPC) as a proxy. The indicator industry value-added current US\$ (IND) is defined as the level of industrial activities that are possible to influence the quality and quantity of water resources in a given country over the selected years. Finally, urbanization (URB, total) is measured based on the total population of a country who are residing in urban centers. Summary of the variables, explanation of their measurements, and the data source are displayed in Table 1.

Table 2 further presents the summary of descriptive statistics for the variables; renewable water resource availability, agriculture, emission of CO<sub>2</sub>, economic growth, industrialization and urbanization using mean, standard deviation, skewness, kurtosis, and Jarque-Bera normality tests. The descriptive statistics are based on a panel of SSA economies sub-classified into three (3) different income level groups (low, lower-middle, and upper-middle income SSA countries). Centering on the whole panel of SSA countries, it is evidenced that water resource availability being the response variable is averagely 9.242 with a dispersion parameter of 1.068. The estimated mean value of H<sub>2</sub>O resource availability implies that throughout the study era, the analyzed sample of SSA nations has a relatively low degree of water availability. On the other hand, the estimated dispersion parameters among the analyzed nations indicate a larger variability concerning water resource availability. Considering the explanatory variables still in the case of the whole panel, industrialization recorded the highest mean value of 21.250 with a dispersion value of 1.651 followed by agriculture (AGR) ( $M = 21.070$ ,  $SD = 1.419$ ), urbanization (URB) ( $M = 15.055$ ,  $SD = 1.589$ ), and then CO<sub>2</sub> emanation ( $M = 7.899$ ,  $SD = 1.573$ ) with economic growth per capita (GDPPC) having the least mean and dispersion coefficients of 6.790 and 1.009 correspondingly.

Comparatively, results obtained for the sub-panels concerning study variables portray disparities and interesting results. Considering the variable H<sub>2</sub>O resource availability, though upper-middle income (UMI) SSA nations have the highest mean value 9.242, there exist a fringe difference amid the three different country categorizations. Averagely, the level of AGR for lower-middle-income (LMI) and low income (LI) is approximately 1.04 and 1.03 times respectively higher compared with that of UMI countries in SSA while marginal difference exists amid the former sub-groups (LMI and LI countries). Averagely, though low levels of CO<sub>2</sub> emissions are evidenced from one country group to the other, UMI countries' mean level of emanations is roughly 1.08 times higher compared with LMI countries and 1.29 times greater than that of LI nations whereas the average level of CO<sub>2</sub> emission in LMI states is 1.21 times more than the emission level in LI economies in SSA. In the case of economic growth, UMI countries in terms of the mean value are almost 1.21 times higher likened to LMI states and almost 1.36 times higher matched to LI countries while LMI countries are branded to be 1.17 times higher than the level of economic growth averagely in LI-SSA nations. Conversely, average industry value (IND) is identified to be approximately 1.02 times higher in UMI countries matched to LMI economies and circa 1.10 times higher while LMI countries are on average observed to be 1.03 times higher likened to LI nations in SSA. Likewise, the average level of urbanization is nearly 1.06 times higher as well as 1.01 times in LMI nations compared with UMI and LI countries correspondingly whereas LI states

**Table 1** Summary of dataset

Variable	Explanation	Source of data
H <sub>2</sub> O	Total renewable water resources per capita (m <sup>3</sup> /inhab/year herein, water resources availability)	FAO Aquastat
AGR	Agriculture value added (current US\$)	WDI
CO <sub>2</sub>	CO <sub>2</sub> emissions (kt)	WDI
GDPPC	Gross domestic product per capita (current US\$)	WDI
IND	Industry value added (current US\$)	WDI
URB	Urban population (total)	WDI

in SSA are also about 1.05 times higher in the level of urbanization averagely than UMI economies. Summarily, the existence of variations though relatively marginal within mean scores indicates there exists some extent of heterogeneity among sampled SSA nations. Also, it can be deduced that, except AGR and URB, upper-middle income SSA countries comparatively had the highest level of H<sub>2</sub>O resources, CO<sub>2</sub>, GDPPC, and IND on average. The implication of this outcome may be that as countries in SSA channel from low-income level to upper-middle-income levels, availability of water resources, emission of carbon, economic growth together with industrialization surges.

Further, for an observed series to be normally distributed, the normal value of skewness and kurtosis is expected to be “zero” and “three” correspondingly (Westfall 2014). Relying

on the aforesaid assertion, a mixture of results is obtained regarding the skewness and kurtosis estimates for the various study variables from one country classification to the other. Specifically, H<sub>2</sub>O together with GDP per capita are evidenced to be negatively skewed whereas URB is on the other hand is positively skewed across all panels. In the case of AGR, CO<sub>2</sub>, and IND, positive skewness is witnessed in both UMI and the whole panel of SSA countries whereas negative skewness is reported from the LMI and LI country classifications. Considering the estimated kurtosis, results variate from one county group to the other since some of the observed series are seen to be approximately mesokurtic (kurtosis value approximately 3), whereas others are reported to be platykurtic (values of kurtosis less than 3) and leptokurtic (kurtosis estimate greater than 3) correspondingly. We can, therefore,

**Table 2** Descriptive data

Panels	statistics	H <sub>2</sub> O	AGR	CO <sub>2</sub>	GDPPC	IND	URB
UMI	Mean	9.858	20.396	9.211	8.622	22.486	14.402
	Std. Dev.	1.190	1.195	1.938	0.402	1.378	1.469
	Kurtosis	3.087	2.868	3.142	3.166	2.765	2.999
	Skewness	− 0.859	1.081	1.408	− 0.645	0.999	1.290
	Jarque-Bera	10.486***	16.613***	28.168***	15.988***	24.322***	23.592***
LMI	Mean	9.400	21.285	8.568	7.146	21.975	15.198
	Std. Dev.	1.103	1.780	1.343	0.665	1.482	1.518
	Kurtosis	3.635	2.516	2.898	2.358	2.976	2.548
	Skewness	− 0.855	− 0.124	− 0.160	− 0.136	− 0.179	0.466
	Jarque-Bera	35.381***	13.146***	10.204***	8.165**	15.368***	11.394***
LI	Mean	9.057	21.076	7.109	6.099	20.438	15.108
	Std. Dev.	0.856	1.094	1.143	0.518	1.383	1.633
	Kurtosis	4.550	3.784	2.388	2.696	2.353	7.154
	Skewness	− 1.218	− 0.250	− 0.183	− 0.358	− 0.144	1.468
	Jarque-Bera	124.004***	10.845**	7.573**	11.574***	7.472**	384.998***
Whole	Mean	9.242	21.070	7.899	6.790	21.250	15.055
	Std. Dev.	1.068	1.419	1.573	1.009	1.651	1.589
	Kurtosis	3.767	3.053	4.522	2.542	3.059	5.087
	Skewness	− 0.715	0.287	0.740	− 0.555	0.142	0.797
	Jarque-Bera	76.557***	39.681***	130.996***	41.900***	22.429***	200.358***

deduce from the aforesaid analysis that none of the kurtosis and skewness values about the study variables across all country groups satisfies the conditions of normality. Thus, we affirm that the observed series is not normally distributed. This is supported by the Jarque-Bera normality test which gives strong evidence to reject the null conjuncture that the observed series follows the normal distribution.

The selected variables for this study were transformed into a natural log. Within the period 2000–2016, 41 countries in sub-Saharan Africa were considered

Additionally, Table 3 outlines the correlation analysis based on the Pearson’s product moment correlation (PPMC) approach together with multi-collinearity test through the tolerance and variance inflation factor (VIF) techniques. Centering on the correlation analysis, results show that except CO<sub>2</sub> emissions, water resource availability (H<sub>2</sub>O) has a statistically significant and negative correlation with AGR and URB, but a positive and palpable linear relationship with GDPPC, and IND. A statistically significant and positive correlation is also evidenced between AGR and CO<sub>2</sub>, IND, and URB correspondingly but negative correlation with GDPPC. Concerning the liaison amid CO<sub>2</sub> and GDPPC, IND and URB distinctly, a positive and statistically significant linear association is identified. GDPPC is further seen to possess a significant and positive correlation with IND but a negative correlation with URB whereas IND is recorded to have a significant and positive correlation with URB. The last variable, URB, is found to possess a positive and statistically significant association with the other variables under study. Highly correlated variables can lead to imprecise estimates of regression which could lead to bias inference (Kock and Lynn 2012). Due to these effects, the study preliminarily went on to perform a multi-collinearity test to verify whether or not variables used in the research model as specified in Eq. (2) are highly interdependent. The multi-collinearity test is thus relevant since it justifies the inclusion or exclusion of explanatory variables within the study model. Statistically, the VIF is substantially less than 10 suggesting a mild association between employed

explanatory variables (no issues of collinearity). All test values of the VIF fell between 0.440 and 1.087. Likewise, the degree of tolerance for all independent variables is far greater than 0.2 indicating that there are no issues of multi-collinearity. Test results from both the VIF and tolerance methods, therefore, justify the inclusion of agriculture production, CO<sub>2</sub> emissions, economic growth, industry development, and urbanization as regressors and key determinants in the H<sub>2</sub>O resource function as proposed in the study.

## Results and discussions

### Cross-sectional dependency and homogeneity tests

Due to the geographical and socio-economic commonalities between sampled countries within the SSA region, it is not hard to believe that these countries may exhibit inter-sectoral reliance in their respective panels which are econometrically likely to cause residual cross-sectional connectedness. Also, it is suggested that in a classical panel data system, non-observed variability is captured by individual unique constants, whether they are assumed to be fix or random. For example, in terms of specific economic variables, preference for heterogeneity between cross-sections can result in individual-specific elasticity. Therefore, ignoring the issues of residual cross-sectional correlation and/or heterogeneity can contribute to skewed estimates and extrapolations. Table 4 therefore unveils the results of cross-sectional dependence and homogeneity tests. As per the findings based on the cross-sectional dependence test, the null hypothesis that there are no issues of residual cross-sectional dependence between series of the country groups is rejected at 1% level of significance across all panels. This, therefore, shows that a shock that occurs within a panel in one of the sample countries will spill over into other countries within the same panel due to strong economic ties. According to Philips and Sul (2003), if residual cross-sectional dependence between countries in a

**Table 3** Pearson’s correlation analysis

Variables		H <sub>2</sub> O	AGR	CO <sub>2</sub>	GDPPC	IND	URB	Test of multi-collinearity	
								Tolerance	VIF
H <sub>2</sub> O	Pearson Corr	1	− 0.226**	− 0.057	0.224**	0.022	− 0.135**	–	–
AGR			1	0.691**	− 0.065	0.307**	0.518**	2.272	0.440
CO <sub>2</sub>				1	0.387**	0.688**	0.575**	1.506	0.664
GDPPC					1	0.452**	− 0.129**	1.906	0.523
IND						1	0.638**	1.387	0.721
URB							1	0.920	1.087

\*\*Correlation is significant at the 0.01 level (two-tailed)



**Table 4** Cross-sectional dependence and homogeneity tests

<b>Cross-sectional dependence test results</b>				
Variable	Whole panel	UMI	LMI	LI
	CD test value	CD test value	CD test value	CD test value
LnH <sub>2</sub> O	35.57***	2.811***	25.53***	9.49***
LnAGR	99.67***	11.64***	34.62***	52.22***
LnCO <sub>2</sub>	89.41***	8.22***	27.61***	50.72***
LnGDPPC	101.54***	12.02***	39.78***	47.92***
LnIND	94.72***	11.91***	29.73***	51.62***
LnURB	112.70***	11.50***	44.31***	54.00***
<b>Homogeneity test results</b>				
Test	Whole panel	UMI	LMI	LI
$\tilde{\Delta}$	23.860***	9.004***	13.932***	8.796***
<i>p</i> value	0.000	0.000	0.000	0.000
$\tilde{\Delta}_{adj}$	27.912***	10.397***	16.087***	10.156***
<i>p</i> value	0.000	0.000	0.000	0.000

\*, \*\*, \*\*\*Indicates significance at 10%, 5%, and 1%,  $\tilde{\Delta}$  and  $\tilde{\Delta}_{adj}$  represents delta tilde and adjusted delta tilde respectively

panel is high, it greatly reduces the efficiency of the estimation outcomes which is often ignored by most econometric modeling researchers. Further, the homogeneity test regarding the values of  $\Delta$  (delta) and  $\tilde{\Delta}_{adj}$  (adjust delta tilde) as well as their respective probability values suggest that there is strong evidence to reject the null hypothesis of homogeneity at a 1% level of significance. This, therefore, portrays econometrically that, there exist issues of individual cross-sectional heterogeneity across all country classifications. Econometrically, evidence of the aforesaid issues within the panel dictates the importance of employing second-generation panel unit root test such as the CADF and CIPS in the next phase of the analysis.

### Panel unit root test

By performing the unit root examination, stationarity of the data could be identified. Table 5, therefore, reports the results from a sample of panel unit root tests at levels and first differences taking into account the case of individual intercept with the trend. With the pre-assumption that there is a common unit process in the panel data employed in the study, we looked at the CIPS and CADF panel unit root tests as they provide efficient results in the presence of residual cross-sectional dependence and heterogeneity. Relying on the results from both CIPS and CADF panel integration order tests, it can be deduced that the null hypothesis of non-stationarity (or series having unit root) is rejected for some variables at levels whereas in the first difference form, some series of variables proved to be statistically insignificant. In other words, a mixture of results on the integration order of variables is evidenced between I(0) and I(1). This trend of the result is witnessed among

all the panels and thus gives the indication that our dataset is not extensive enough to make the unit root effect concerning the study variables noticeable. Therefore, the unit root tests conducted may only be a reference for our test but could not be relied on so much because it does not clarify the stationarity issues unswervingly. The inconsistencies of the integration order of the study variables both at level forms as well as first difference further stress that co-integration relationship amid the variables is most likely not to be formerly detected, hence in the presence of this issue, the PMG/ARDL estimation approach is implemented in the subsequent section to estimate the long-run liaison. This is supported by Pesaran and Shin (1999) who reported that the PMG/ARDL approach is superior regardless of whether the underlying regressors exhibit I(0), I(1), or a mixture of both integration orders.

### Long-run estimation results

A vital corollary of this empirical research is the estimation of long-run parameters corresponding to the explanatory variables (AGR, CO<sub>2</sub>, GDPPC, IND, and URB) to estimate their respective level of affiliations in the long run. This as a result that helps in measuring the response variable (H<sub>2</sub>O) elasticities concerning the explanatory variables. Relying on these assertions, the study as already mentioned employed the PMG/ARDL approach to be able to estimate the long-term relationship amid the study variables since a mixture of integration order outcomes (I(0) and I(1)) both at levels and when differenced have been witnessed (see Table 5). Table 6 therefore presents the long-term estimation results of the PMG/ARDL method. Following the outcomes presented, AGR is evidenced to have a negative statistically significant influence on H<sub>2</sub>O in the LMI and LI subpanels while a positive significant affiliation is recorded in the whole panel countries in SSA. This indicates that a unit surge in AGR is most likely to decrease H<sub>2</sub>O in the LMI and LI panels by – 0.253 and – 0.679 respectively whereas upsurge in AGR enhances the availability of H<sub>2</sub>O in the whole panel by 0.177. Centering on the significant relationships, the negative effect of AGR on H<sub>2</sub>O may be due to the reason that there exists high demand for food to feed the growing population in both LMI and LI countries in SSA. Relying on this fact, several tons of water is withdrawn to irrigate the farms. Hence, to increase food production, agrochemicals are applied to the plants which often drain into nearby surface water resources, while some sip into the ground and affect the water table. Surprisingly, the positive liaison witnessed amid AGR and H<sub>2</sub>O although unexpected may be as a result of farmers in most countries in SSA maintaining a buffer zone so that they do not farm at certain meters close to water bodies. Another reason to this may be that most farmers in this region likely do not depend so much on available water resources for irrigation since literature has made it clear that most farmers in Africa rely

**Table 5** Panel unit root test

Variable	Whole panel		UMI		LMI		LI	
	Level	1st Diff	Level	1st Diff	Level	1st Diff	Level	1st diff
<b>CIPS</b>								
LnH <sub>2</sub> O	-4.30***	-5.79***	-3.25***	-5.36***	-4.35***	-5.67***	-3.78***	-5.35***
LnAGR	-3.25***	-4.04***	-2.40	-3.72***	-3.49***	-4.07***	-2.95***	-4.00***
LnCO <sub>2</sub>	-2.24	-3.66***	-1.85	-3.86***	-2.05	-3.61***	-2.43	-3.79***
LnGDPPC	-2.87***	-3.38***	-2.68	-3.34***	-3.05***	-3.41***	-2.65*	-3.95***
LnIND	-2.64*	-3.58***	-2.64	-3.37***	-3.07	-3.54***	-2.51	-4.05***
LnURB	-1.73	-2.37*	-3.49***	-1.84*	-0.14	-1.78*	-2.45	-2.50*
<b>CADF</b>								
LnH <sub>2</sub> O	-1.67	-2.67***	-1.58	-2.28**	-1.94	-3.13***	-0.10	-2.49***
LnAGR	-3.04***	-3.24***	-2.11	-2.69**	-3.01***	-2.87***	-2.84***	-3.19***
LnCO <sub>2</sub>	-1.97	-2.77***	-1.41	-4.35***	-1.74	-2.35***	-2.05	-2.70**
LnGDPPC	-2.71***	-2.76***	-2.88**	-2.33***	-3.47***	-3.23***	-2.22	-2.66**
LnIND	-2.51**	-2.65**	-2.80	-3.29**	-2.93***	-2.73**	-2.27	-2.50*
LnURB	-3.21	-2.87***	-02.65	-2.16***	-0.30	-1.40**	-3.68***	-2.87***

1st Diff means 1st Difference

\*, \*\*, \*\*\*significance at 10%, 5%, and 1%

on rains to irrigate their farms. The negative effect of AGR on H<sub>2</sub>O supports the report of FAO (2017) and agrees with Karamage et al. (2016) that river basins such as Kegeza, Akagera, and the Nyabarongo in Africa have been recorded to be among water bodies that are extremely polluted in the world due to agricultural production, urbanization, and industrialization. However, results about the positive association amid AGR and H<sub>2</sub>O in the whole panel contradict with the Global Food Security (GFS, 2015) report that a higher proportion of water pollution has come from agricultural sources.

Again, taking into account the nexus amid CO<sub>2</sub> emanation and H<sub>2</sub>O resource, a positive significant impact from CO<sub>2</sub> emission on H<sub>2</sub>O is witnessed in the case of UMI and whole panels of SSA nations. On the contrary, the LMI and LI countries in SSA region are characterized by the negative

significant impact. This, therefore, insinuates that a unit change in CO<sub>2</sub> emissions enhances the H<sub>2</sub>O in the UMI and whole panels of SSA countries by 0.272 and 0.299 correspondingly. However, a reduction in H<sub>2</sub>O by -0.048 and -0.052 is found when a unit rise is applied to CO<sub>2</sub> emissions in the LMI and LI subpanels. The negative relationship between CO<sub>2</sub> emission and H<sub>2</sub>O stems from the fact that globalization associated with urbanization and economic development in both LMI and LI SSA countries has led to the production of several goods and services to satisfy demands of the growing population. By this, emission of nitrogen and methane from farms as well as air pollution from the urban centers and industries compound to harm the atmosphere. The normal climatic conditions, therefore, become distorted, and this results in flooding, and at other instances, drought. Precisely,

**Table 6** Results of the PMG/ARDL long-run estimation

Dependent variable: H <sub>2</sub> O resource availability								
Explanatory Var.	UMI	Prob.	LMI	Prob.	LI	Prob.	Whole	Prob.
LnAGRI	-0.386	0.103	-0.253***	0.001	-0.679***	0.004	0.177**	0.027
LnCO <sub>2</sub>	0.272***	0.000	-0.048**	0.049	-0.052***	0.000	0.299***	0.000
lnGDPPC	-0.205	0.5810	-1.494***	0.000	0.963***	0.003	-0.732***	0.000
lnIND	-0.856***	0.000	-0.807***	0.000	-0.242	0.109	-0.783***	0.000
lnURB	4.086**	0.041	-1.637***	0.000	-0.534***	0.010	-0.060*	0.051
ECT	-0.369***	0.000	-0.322***	0.003	-0.172***	0.000	-0.331***	0.000
Hausman test	5.322	0.102	4.891	0.422	1.968	0.854	6.021	0.304
CD-test	2.120***	0.000	2.209***	0.000	1.628**	0.013	2.746***	0.000

\*, \*\*, and \*\*\*significance levels at 1%, 5%, and 10% correspondingly

the positive effect of CO<sub>2</sub> emission on the availability of water is bewildering to the authors, in the sense that, emanations from CO<sub>2</sub> emissions have done more harm than good to water resources and the environment of SSA countries. Carbon emission pollutants therefore do not only alter the climatic conditions but also makes the rains often toxic due to the excessive emissions into the atmosphere. These toxic rains drain into water bodies and affect humans as well as the ecosystem within the catchments that depend on it for survival. The negative influence of CO<sub>2</sub> emissions on H<sub>2</sub>O is in line with the report of Singh et al. (2014) and Mapulanga and Naito (2019) whereas the positive significant impact of CO<sub>2</sub> emission on H<sub>2</sub>O contrarily contradicts with the results of Masese et al. (2012).

Moreover, the impact of GDPPC on H<sub>2</sub>O varies from one country group to the other. In detail, excluding UMI panel, a statistically significant negative impact of GDPPC on H<sub>2</sub>O is found in LMI and whole panels respectively while on the side of LI countries, the former and latter variables as characterized by a positive statistically significant bond. Notably, GDPPC in the context of UMI countries in SSA is reported as a negative influencer of H<sub>2</sub>O but possess an insignificant estimate. To further explain the variation of effects concerning GDPPC on H<sub>2</sub>O, we deduce that a unit rise in GDPPC depreciates H<sub>2</sub>O in the panel of SSA nations including LMI countries by 0.732 and 1.494 correspondingly, while an improvement by 0.963 is found specifically in LI nations. Economically, the negative influence of GDPPC on H<sub>2</sub>O could be that increase in the consumption of water for various purposes among other factors in the whole panel of SSA nations (including LMI states) stems from the change in consumption patterns from indigenous agricultural practices to water-intensive agricultural mechanization, and low-water intensive products to higher intensive products by industries. This supports Ngarava et al. (2019)'s study that improvement in the living conditions of citizens can have a negative influence on the environment since they can afford to purchase water-intensive products while others misuse the water because it is available, and they can pay for the water tariffs. Nonetheless, the positive influence from GDPPC could also be that as the standard of living of people increases, they can afford water-efficient products at the municipal, industrial, and agricultural sectors. This may include water-efficient equipment in apartments and factories as well as water-efficient irrigation pumps. Results about the negative influence of GDPPC on H<sub>2</sub>O align with the findings of Pullanikkatil and Urama (2011) and Stoyanova and Harizanova (2019). In the case of the positive and palpable affiliation between GDPPC on H<sub>2</sub>O, our study agrees with Mcgrane (2015) that economic development has a positive influence on water resources. Again, OECD (2016) has said that economic growth can facilitate opportunities for policy reforms, strengthen institutions for water management, and finance for investments in water-related technologies,

infrastructure, and information systems. Nonetheless, the findings of Ngoran et al. (2016) contradict this assertion and have revealed that economic growth in SSA is mainly dependent on water resources.

Furthermore, IND reportedly has a negative statistically significant influence on H<sub>2</sub>O across all panels. This indicates that irrespective of the level of income about a country in SSA region, a unit surge in IND is more likely to reduce H<sub>2</sub>O by  $-0.856$ ,  $-0.807$ ,  $-0.242$ , and  $-0.783$  correspondingly. The evidence of the decline in H<sub>2</sub>O due to IND stems from the fact that most companies in developed countries escape from heavy taxes that are imposed on CO<sub>2</sub> emission and set up their factories in developing countries (of which countries in SSA are not exceptional) where there are no or flexible carbon taxes. Aside from air pollution, solid and liquid wastes from the industries are often disposed of into nearby water resources without proper treatment. These activities thus affect the quality of the water resources making it unsuitable for consumption by humans and the ecosystem. This result aligns with the findings of Yoon and Heshmati (2017). Our study also corresponds with Mudhoo et al. (2015) that the increased reliance of most industries on non-renewable energy and improper disposal of solid and liquid waste products have become a common practice in most of the SSA countries. Our result nonetheless is not in tandem with the evidence of Wei et al. (2012) and Kalami et al. (2013).

Finally, the estimated PMG results showed that the coefficient of URB in UMI panel has a substantial positive effect on H<sub>2</sub>O whereas in the case of LMI and LI together with the whole panel, URB negatively influenced H<sub>2</sub>O. A unit increase therefore in URB is highly expected to increase H<sub>2</sub>O in UMI countries in SSA by 4.086 while a unit surge is estimated to debilitate H<sub>2</sub>O in the LMI, LI, and whole panels by  $-1.637$ ,  $-0.534$ , and  $-0.060$  correspondingly. The economic implication concerning the decline in H<sub>2</sub>O resulting from URB is that as the population in urban centers from the whole panel including LMI and LI nations increase, there is a high demand of water for various consumption purposes (domestic, industrial, and agricultural purposes). That is, the preference of different types of agricultural produce, processed goods, and other economic activities results in water stress. Therefore, a further increase in urban growth without sustainable management of water resources will result in low volume and quality of the available water resources. On the other hand, the positive impact of URB on H<sub>2</sub>O could be that authorities in the UMI countries in SSA provide some sort of urban schemes that are capable of managing water withdrawal and consumption such as wastewater treatment systems, industrial and municipal water-efficient technologies. Comparatively, our result concerning the negative affiliation amid H<sub>2</sub>O and URB is in line with the result of Liyanage and Yamada (2017), Serge and Sebartha (2018), and Bigelow (2017). However, the

positive liaison amid URB and H<sub>2</sub>O agrees with Mcgrane (2015) but contrary to the outcome of Sharma (2017).

More importantly, the error correction terms (ECTs) of the variables; H<sub>2</sub>O, agriculture development, emission of CO<sub>2</sub>, gross domestic product per capita, industrial development, and urbanization have speeds of adjustment<sup>2</sup> of 2.710, 3.156, 5814, and 0.751 for UMI, LMI, LI, and the whole panel of SSA nations correspondingly. This as a result gives the impression that the study variables in each panel very speedily respond to deviations in the long-term equilibrium. Furthermore, a post-estimation test based on the Hausman poolability test indicates that there is strong evidence to accept the null conjuncture of homogeneous restrictions since the respective probability values for the various Hausman test values are greater than 1%, 5%, and 10% levels of significance across all panels. This means that the PMG estimator is suitable and robust for estimating the long-term pooling coefficients within the panel ARDL model in each panel correspondingly. Despite the significant result of the variables of interest, the PMG-ARDL method in Table 6 together with MG-ARDL approach (from Table 7) disregards contemporaneous correlations across the country groups employed, which is caused by unobserved factors. Ignoring these factors can lead to less consistent estimators (Baltagi, 2014). This is shown from the CD test (Pesaran) result for each model (PMG-ARDL and MG-ARDL) indicating a high value of cross-sectional dependence in the residual term and clearly reject the null conjuncture of weakly cross-sectional reliance. The contemporaneous correlations are thus expected to diminish when the CCEPMG through the CS-ARDL model is introduced.

The current study examined the robustness of the PMG panel ARDL estimation approach through the CCEPMG/CS-ARDL and the MG estimators correspondingly. Table 7 therefore outlines the results of the CS-ARDL and MG estimation methods. Results of the long-run elasticities of both CS-ARDL and MG estimators are interestingly evidenced to be in tandem with the estimates of PMG/ARDL. Nonetheless, relatively high long-run elasticities are obtained via the CCEPMG/CS-ARDL method. The CCEPMG/CS-ARDL tends to give larger elasticities compared with the MG. With the exception of CCEPMG via the CS-ARDL estimation model, the outcome pertaining to the MG-ARDL model still suffers from issues of residual cross-sectional correlations. This therefore infers that the issue of strong residual cross-sectional dependence is resolved concerning the CD test results of CCEPMG/CS-ARDL method. Additionally, this supports the theoretical view that the CCEPMG/CS-ARDL long-run estimation technique is robust to issues concerning strong cross-sectional residual correlations.

<sup>2</sup> The speed of adjustment is computed based on the inverse ratio of the Error Correction Terms (ECTs) absolute terms

## Panel causality test results

Estimation of the long-term affiliation amid the study variables does not unveil the path of causal affiliations between H<sub>2</sub>O and its proposed determinants. Hence, the causal connection among H<sub>2</sub>O, CO<sub>2</sub> emission, GDPPC, IND, AGR, and URB is finally explored in this section of the empirical analysis using a panel causality technique robust to residual heterogeneity and cross-sectional reliance<sup>3</sup>. To make the interpretation more ostensible, Fig. 1 presents the summary of the five-way causal affiliations between H<sub>2</sub>O and each of the explanatory variables<sup>4</sup>. Mixed outcomes on the causal relationships are evidenced between the variables, as some causal affiliations are homogeneous across all panels whereas others differ from one country group to the other. Specifically, a unidirectional causal link was found moving from AGR to H<sub>2</sub>O in UMI, LMI, and LI panels while a causal link rather from H<sub>2</sub>O to URB was witnessed in the whole panel. The one-way causal link further implies that AGR is associated with increased dependence on agrochemicals such as fertilizers and excessive withdrawal of water for irrigation specifically in all countries within the sub-panels. According to Pare and Bonzi-Coulibaly (2013), the continuous use of these agrochemicals deteriorates water resources within the SSA bloc. This aligns with the work of Reynolds et al. (2015) whose assessment indicated that the production of food crops has diverse and often significant effects on the water resources. Water resource availability is one of the main components of increasing agricultural production. However, any deterioration of the quantity and quality of the resource will negatively affect the quest to achieve sustainable water resource availability. Comparatively, excluding the whole panel, a unilateral causal connection in LMI and LI panels extends from CO<sub>2</sub> to H<sub>2</sub>O whereas a bi-directional affiliation was found in the UMI panel. Based on the study of Singh et al. (2014) the unilateral causality that runs from the former (CO<sub>2</sub>) to H<sub>2</sub>O may be due to urbanization, industrial production, agricultural production, and other land-use land cover activities in both LMI and LI SSA countries. As these activities emit greenhouse gases and other dangerous pollutants into the atmosphere, the ozone layer depletes, leading to long months of drought, which dries up the available water resources. This aligns with the study of Urama and Ozor (2010). On the side of the bilateral connection, water resources may influence climate change in the sense that water resources evaporate and condense in the atmosphere and fall back as rain which increases the volume of the water bodies. However, when the available water resources are dried up, only a little evaporation will take

<sup>3</sup> Considering the causal links between variables, the study primarily centered on the direction of causations amid the response variable and each of the explanatory variables distinctly but ignored the causations among the independent variables.

<sup>4</sup> Details of Fig. 1 has been provided in the Appendix section as Table 9

**Table 7** Robustness test

Variable	UMI	Prob.	LMI	Prob.	LI	Prob.	Whole panel	Prob.
CCEPMG/CS-ARDL long-run estimation results								
LnAGR	− 0.105	0.134	− 0.212**	0.017	− 0.284***	0.000	0.571***	0.000
LnCO <sub>2</sub>	0.341***	0.000	− 0.225***	0.000	− 0.227***	0.001	0.299**	0.030
lnGDPPC	− 0.027	0.102	− 0.104**	0.011	0.661***	0.000	− 0.315***	0.000
lnIND	− 0.224***	0.000	− 0.183***	0.000	− 0.016	0.299	− 0.122**	0.047
lnURB	2.029**	0.012	− 0.904***	0.000	− 0.210***	0.002	− 0.109*	0.065
ECT	− 0.201	0.000	− 0.325***	0.000	− 0.335***	0.000	− 0.294***	0.000
CD-test	− 2.635	0.201	− 2.005	0.128	− 1.659	0.137	− 0.992	0.515
MG-ARDL long-run estimation results								
LnAGR	− 0.225	0.106	− 0.314*	0.053	− 0.682***	0.000	0.217**	0.050
LnCO <sub>2</sub>	0.264***	0.007	− 0.311*	0.097	− 0.300***	0.000	0.169*	0.092
lnGDPPC	− 0.116	0.314	− 0.433*	0.059	0.441**	0.030	− 0.674**	0.031
lnIND	− 0.4641***	0.000	− 0.382*	0.097	− 0.024	0.137	− 0.181*	0.058
lnURB	0.6401**	0.055	− 1.027***	0.000	− 0.295**	0.013	− 0.280*	0.084
ECT	− 0.618***	0.000	− 0.548***	0.000	− 0.492***	0.000	− 0.402***	0.000
CD-test	3.401***	0.000	3.052***	0.000***	2.016***	0.000***	2.930***	0.000

\*, \*\*, and \*\*\* represents significance levels at 1%, 5%, and 10% correspondingly

place which may result in little or no rains at all. This assertion aligns with the study of Chan et al. (2016), who made a broad assessment of the hydrological cycle and cities.

In the context of causality amidst H<sub>2</sub>O-GDPPC, no mutual relationship existed in the whole panel, but the sub-panels had a unilateral causality running from GDPPC to H<sub>2</sub>O. In reference to the study of Wik et al. (2008), the unidirectional extension from GDDPC to H<sub>2</sub>O may be due to the reason that demand for water increases as more acreages of land are cultivated for food production, and diverse industrial activities rise to increase GDP of SSA countries. Ngoran et al. (2016) thus said that economic growth tends to decrease the volume of water resources in SSA, as water is needed for various purposes, be it industrial, agricultural, or other consumptive purposes. Considering H<sub>2</sub>O and IND linkage, a unilateral causality was found from the latter (IND) to the former variable (H<sub>2</sub>O) in the whole and LI panels whereas in the case of the UMI panel, a bidirectional connection was evidenced. For further explanation, a one-sided link from IND to H<sub>2</sub>O means that in SSA countries that are classified to be LMI and LI, water is needed for various uses in factories like the cooling of machines and food processing, among others. But these activities exert pressure on the water resources. Basson (2011) has reported that in South Africa, for instance, water quality is worsened because large quantities of effluents from factories, rural, and urban areas with inadequate sanitation services flow into river bodies. On the other hand, the bidirectional causation evidenced in UMI countries within the SSA panel could be that although industrial activities cause deterioration of the value and quantity of water resources through the consumption and approaches of discharging

wastewater, most of the factories may be owned by foreigners who may know some innovative technologies in treating the wastewater before discharging into the water bodies. That is, they may have some good research and development (R&D) systems in place for managing the water, which is withdrawn for their activities. This aligns with the study of Awolusi et al. (2017). It is, therefore, very important for companies in SSA to invest in R&D to acquire more innovative technologies to enhance sustainable water use without polluting the quality or decrease the quantity. Concerning the URB-H<sub>2</sub>O nexus, evidence of one-sided causality is found moving from URB to H<sub>2</sub>O in the whole panel while a two-sided causal connection is evidenced amid the mentioned variables in the LI panel of SSA countries. Surprisingly, no sign of causal effect is observed in UMI and LMI panels among URB and H<sub>2</sub>O. The evidence of no mutual direction of causation amid the URB and H<sub>2</sub>O in both UMI and LMI groups of countries in SSA is unexpected and not convincing since literature, for instance, Okello et al. (2015), has reported that urban growth and its associated socio-economic activities put pressure on water resources given that the urban population depends on the urban streams for various consumptive purposes. Likewise, Santos et al. (2018) have posited that urbanization has influenced most water resources in SSA.

## Conclusion and policy recommendations

Sustainable water resource availability is essential to the growth of any economy because the water stress rate for each country has a relation with socio-economic factors.

Consequently, the availability and access to water management have been a concern for policymakers as well as other stakeholders especially in the SSA region, hence their intense effort to find solutions to the increasing stress on water and water scarcity. Relying on this background which is much in line with the literature, researchers in their involvement in this current paper tailed to scrutinize the key events contributing to water resource availability as well as the causal affiliations amid these key determinants and total renewable water resources as a proxy of water resource availability. A panel regression model that reflects  $H_2O$  therefore, is used to analyze 41 SSA countries sub-paneled into low income, lower-middle-income, and upper-middle-income states during the period 2000–2016 to achieve the study goal. Taking into account potential issues of residual cross-sectional reliance as revealed by the Pesaran's CD test, this recent study employed robust panel econometric approaches to prevent erroneous results in the presence of the aforesaid issue which most researches in related fields pay less attention to. Consequently, the main outcomes derived from the employment of various methods are summarized as follows in a step-by-step manner:

1. Relying on the integration order (stationarity test) assessment of individual variables employed in the study, the CADF and CIPS panel unit tests unveiled that integration order of the variables was not consistent since the null hypothesis of non-stationarity of some series was rejected at levels (meaning some variables were  $I(1)$  at levels) whereas in the first difference form, other variables were reported to be non-stationary (meaning some variables were  $I(0)$  in their first difference order). Econometrically, due to the inconsistencies among the integration order of the variables, formerly detecting cointegration affiliations amid the variables is less likely to occur; thus, this led to the application of the PMG/ARDL approach to further estimate the long-run relationship among the variables in the presence of the aforesaid issue.
2. Estimates from the PMG/ADRL approach demonstrated interesting as well as varying outcomes concerning how GDPPC,  $CO_2$  emissions, AGR, IND together with URB as explanatory variables influence  $H_2O$  in SSA. Regarding disparities in the estimation findings, AGR had a significant negative effect on  $H_2O$  both in LMI and LI panels whereas in the whole panel, a positive significant impact is witnessed. Likewise,  $CO_2$  emissions had a significant positive liaison with  $H_2O$  resource in UMI and the whole panel while on the side of LMI and LI panels, an adverse influence was identified. Moreover, except the UMI group, GDPPC and  $H_2O$  in both LMI and the aggregated panel were characterized by significant negative affiliation, but on the contrary, the former (GDPPC) palpably influenced  $H_2O$  in LI panel.

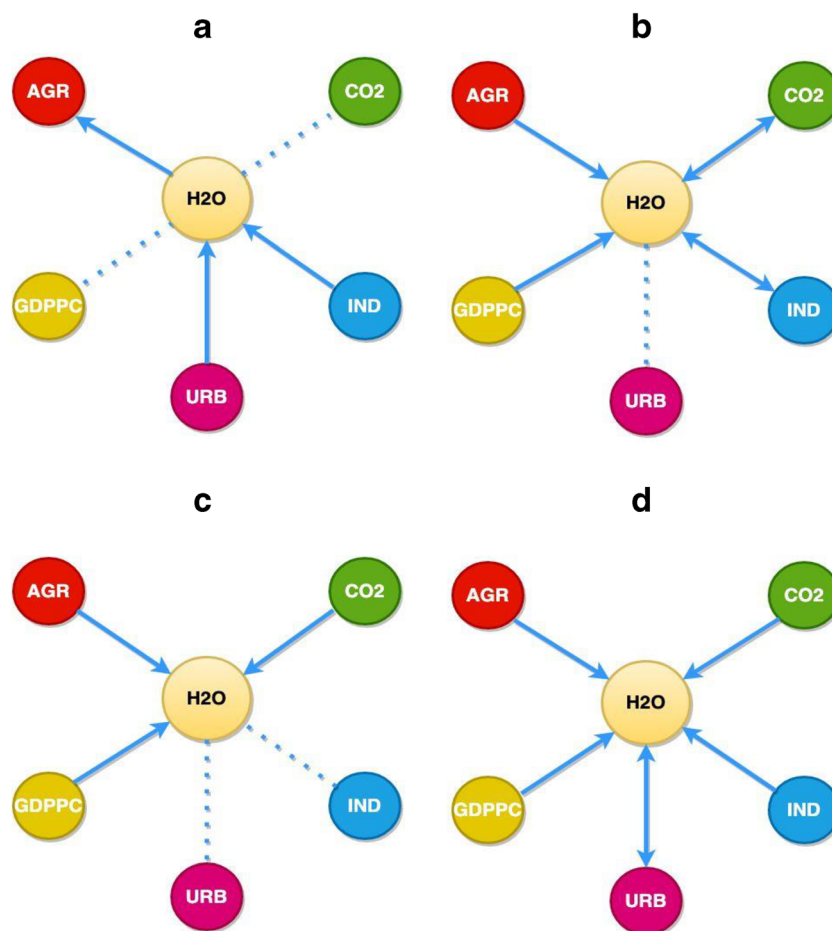
Evidently, excluding the LI panel where the insignificant effect was witnessed, industrial development in relation  $H_2O$  was observed to have a significant influence in UMI, LMI, and the whole panel of sampled SSA countries. Homogeneously, URB across all the panels showed a substantial negative influence on  $H_2O$  although the weight of effect varied from one panel to the other. Finally, URB was evidenced to have a positive significant liaison with  $H_2O$  in UMI panel, nonetheless, but a substantial negative connection was found in the whole panel together with LMI and LI panels of SSA nations. Post-estimation test based on the Hausman poolability test showed that the estimated  $H_2O$  model using PMG/ARDL approach is suitable for the long-term pooling coefficients since the null hypothesis of homogeneous restrictions is not rejected among all panels. Notably, the checks for robustness depicted consistent results via the CCEPMG/CS-ARDL and MG estimation approaches.

3. Centering on the path of causation amid  $H_2O$  and each of the proposed determinants (economic growth,  $CO_2$  emissions, agriculture production, industrial development, and urbanization), a mixture of results was obtained from one income group to the other. The D-H causality test summarily unveiled that AGR is unilaterally linked to  $H_2O$  in the sub-panels (UMI, LMI, and LI) whereas for the whole panel of SSA sampled countries, the causal affiliation was vice-versa. Also, except the whole panel,  $H_2O$  and  $CO_2$  were bidirectionally connected in the UMI panel of SSA countries while a one-way link was identified moving from  $CO_2$  to  $H_2O$  in the case of LMI and LI panels. Moreover, sampled SSA countries within the LI, LMI, and UMI panels were characterized by a unidirectional link from GDPPC to  $H_2O$  whereas considering the whole panel, no sign of causation was found. Focusing on  $H_2O$ -IND causal nexus, the whole panel together with LI sub-groups portrayed one-way causation from IND to  $H_2O$  whereas in the UMI panel, a bi-directional causal link is evidenced. Finally, for  $H_2O$ -URB nexus, the whole panel is characterized by a unilateral causal link from URB to  $H_2O$  while the LI panel showed a two-way causal relationship amid the aforementioned variables. No sign of causal affiliation existed between URB and  $H_2O$  in UMI and LMI countries.

Generally, the results from this analysis will provide more insight to clarify the relationship between the variables analyzed and also assist policymakers in developing better policies based on the study variables. The empirical findings as discussed have identified some policy recommendations as follows:

1. With the existence of cross-sectional connectedness among individual cross-sections within the panel of

**Fig. 1** Summary of the five-way causal connections amid H<sub>2</sub>O and each of the explanatory variables (AGR, GDPPC, URB, IND, and CO<sub>2</sub>) distinctly. Note that, →, ↔, and — represent one-way, two-way, and no directional causality respectively. **a–d** The country panels which includes the whole panel, upper middle income, lower middle income, and low-income panels respectively



- SSA nations, our study recommends that there should be cooperation among all the blocks (West Africa, East Africa, and the South African countries) on the need to protect and promote sustainable water resources in Africa.
- Also, within all the panels that were studied, urbanization is profoundly influencing the available water resources in SSA. Relying on this outcome, we urge policymakers in the various countries in SSA to promote capacity building on the need to reduce population growth since a large population will demand more water for consumption. Again, community members should be encouraged to store water in reservoirs and water storage containers so that they can have enough supply of water throughout the year. Policymakers across SSA are further recommended to ensure that adequate infrastructure is provided in the rural areas so that the rural-urban migration will reduce to enhance water resource availability, especially in the urban centers.
  - Further, our findings revealed that the rate of the significant negative influence of agricultural production, CO<sub>2</sub> emission, GDPPC, industrial growth, and urbanization on water resources availability in SSA is not subject to country-specific income level. The researchers of this

study, therefore, recommend that each country based on a specific stage of development in terms of income levels need to effectively develop policies that will protect its available water resources, especially the limited freshwater. This can be done by putting heavy taxes on carbon emission, treat agricultural and industrial liquid waste before discharging into water bodies, and finally, citizens can be educated through print and electronic media on how water in the households should be used without wasting it.

- Again, as agricultural production and industrial development harness the economic growth of every country, it should however not be to the detriment of available water resources. It is, therefore, essential for governments, policymakers, and other international organizations who bring foreign direct investments into SSA to have proper water demand management plans, and water resources should be consumed wisely, whether for domestic, industrial, or agricultural purposes without compromising the need for the future generation.
- Furthermore, irrespective of the income level of a country within the SSA region, this study based on the empirical findings generally recommends the effective practice of

afforestation. It is believed that trees especially at the buffer zones protects the surface water resources and harness the formation of clouds which falls back as rains.

6. Moreover, policymakers should collaborate with some developed countries such as USA, Israel, China, and Japan who have a lot of technologies in water treatment and water resource management to educate them on how to use less water to produce more without polluting the resource.
7. Furthermore, policymakers in SSA should include rain-water harvesting, recycling, and wastewater treatment in both current and future policy reforms. By this, municipal recycled water can be used for domestic purposes such as flushing of toilet while wastewater from treatment plants can be used to cool machines at the industries and for irrigation purposes.

### Theoretical and methodological implications

Theoretically, the findings obtained in this study rely on two main theories which include the sustainable development theory together with ecological modernization theory. Specifically, the sustainable development theory aims at ensuring continuous availability of water resources and at the same time reduce pollution. The implication of this theory (sustainable development theory) concerning our findings is that as agricultural activities, industry, economic growth, and urbanization increase, water resource availability should at the same time be managed sustainably. Thus, governments and policymakers are commended to adopt water-saving technologies in factories, on the farms and as well make sure that future policies for building plans will include use of water-saving technologies such as rain gutters to harvest rainwater. Also, the ecological theory asserts that issues concerning the environment develop from one stage to the other. The implication of this theory on countries in SSA based on our findings is that pressures from agricultural activities, industry, economic growth, emission of carbon dioxide, and urbanization on water resources develop in different forms of negative issues such as the increase in water-related health problems due to poor water quality and climate change which results in unexpected flood or drought. Nonetheless, the assurance is that policymakers can rectify these situations by introducing citizens within countries in the SSA to less water input production, import virtual water, and adopt buffer zone policies.

Methodologically, the study employed the PMG/ARDL method to provide a new perceptible on the identification of factors affecting water resource availability in SSA countries based on income levels. The proposed determinants (key

drivers) have a significant impact on water resource availability in different dimensions based on income level groups, which provide a useful reference for both the private and public sectors in the various SSA regions irrespective of developmental stages to take appropriate measures to improve the level of sustaining water resource availability. Outcomes from the method employed provide a good reference for countries within the SSA region to conduct new sustainable decision-making policies, issue a sustainable regulation, and review a sustainable design (plan) regarding the availability of water resources. Inferentially, countries within SSA can easily find a solution to develop a sustainable water management scheme from the perspective of economy, society, resource and environment, engineering, and project management.

**Authors' contribution** Ethel Ansaah Addae, Dongying Sun, and Isaac Adjei Mensah: conceptualization, writing-original draft preparation, methodology. Ethel Ansaah Addae, Isaac Adjei Mensah, and Mohammed Musah: writing-reviewing and editing. Isaac Adjei Mensah, Ethel Ansaah Addae, and Mohammed Musah: Data curation, software, visualization. Ethel Ansaah Addae, Dongying Sun, Hatem Jemmali, Claudia Nyarko Mensah, Florence Appiah-Twum: investigation, reviewing. All the authors have read and approved the submission of this article.

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**Data availability** Data pertaining to the study variables can be obtained from <https://databank.worldbank.org/source/world-development-indicators> and <http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en>

### Compliance with ethical standards

**Competing Interests** The authors declare that they have no conflict of interest.

**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.

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**Abbreviations** CADF, cross-sectional augmented dickey-fuller; CIPS, cross-sectional Im, Pesaran and Shin; PMG/ARDL, pooled mean group/autoregressive distributed lag; CCEPMG/CS-ARDL, common correlated effect pooled mean group/cross-sectional- autoregressive distributed lag; GDPPC, gross domestic product per capita; AGR, agriculture; IND, industrialization; URB, urbanization; LMI, lower middle income; LI, low income; UMI, upper middle income; H<sub>2</sub>O, resource-water resource; D-H, Dumitrescu and Hurlin



## Appendix

**Table 8** List of total sampled countries for all panels

Panel	Total sampled countries	List of samples countries
UMI	Five (5) countries	Botswana, Mauritius, Gabon, South Africa, Namibia
LMI	Fifteen (15) countries	Cabo Verde, Angola, Congo rep., Cameroon, Eswatini, Cote d'Ivoire, Kenya, Ghana, Mauritania, Lesotho, Zimbabwe, Nigeria, Senegal, Zambia, Sudan
LI	Twenty-one (21) countries	Burkina Faso, Benin, Chad, Burundi, Madagascar, Comoros, Congo DR, Gambia, Ethiopia, Guinea Bissau, Guinea, Liberia, Malawi, Mali, Niger, Mozambique, Togo, Sierra Leone, Rwanda, Tanzania, Uganda
Whole panel	Forty-one (41) countries	Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Chad, Comoros, Congo Democratic Republic, Congo republic, Cote d'Ivoire, Ethiopia, Eswatini, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Liberia, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia, Zimbabwe

**Table 9** Dumitrescu-Hurlin panel causality test results

Null hypothesis	Whole	UMI	LMI	LI
$\ln \text{AGR} \rightarrow \ln \text{H}_2\text{O}$	1.534 (0.21)	1.248 (0.05)*	0.601(0.03)**	2.312(0.01)***
$\ln \text{H}_2\text{O} \rightarrow \ln \text{AGR}$	0.820 (0.00)***	0.514 (0.442)	0.7796 (0.41)	0.923(0.54)
$\ln \text{CO}_2 \rightarrow \ln \text{H}_2\text{O}$	0.981 (0.11)	0.956 (0.09) *	0.626 (0.05)**	1.259 (0.06) *
$\ln \text{H}_2\text{O} \rightarrow \ln \text{CO}_2$	0.966 (0.47)	0.633 (0.03)**	0.655(0.28)	1.283 (0.81)
$\ln \text{GDPPC} \rightarrow \ln \text{H}_2\text{O}$	1.480 (0.32)	1.859 (0.03)**	0.558 (0.06)*	2.092(0.03)**
$\ln \text{H}_2\text{O} \rightarrow \ln \text{GDPPC}$	0.815 (0.22)	0.381 (0.32)	0.565 (0.20)	1.109 (0.86)
$\ln \text{IND} \rightarrow \ln \text{H}_2\text{O}$	1.208 (0.03) **	1.899 (0.00)***	0.433 (0.10)	1.634 (0.08)*
$\ln \text{H}_2\text{O} \rightarrow \ln \text{IND}$	1.091 (0.18)	0.638 (0.04)**	0.744 (0.36)	1.4643 (0.50)
$\ln \text{URB} \rightarrow \ln \text{H}_2\text{O}$	1.375(0.04)**	0.630 (0.51)	0.732 (0.35)	2.042 (0.04)**
$\ln \text{H}_2\text{O} \rightarrow \ln \text{URB}$	1.179 (0.99)	0.572 (0.48)	1.150 (0.95)	1.345 (0.05) *

Values in parenthesis () indicate probabilities

\*significance at the 10% level; \*\*significance at the 5% level; \*\*\*significance at the 1% level

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