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# Predictors of access to safe drinking water: policy implications

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## ABSTRACT

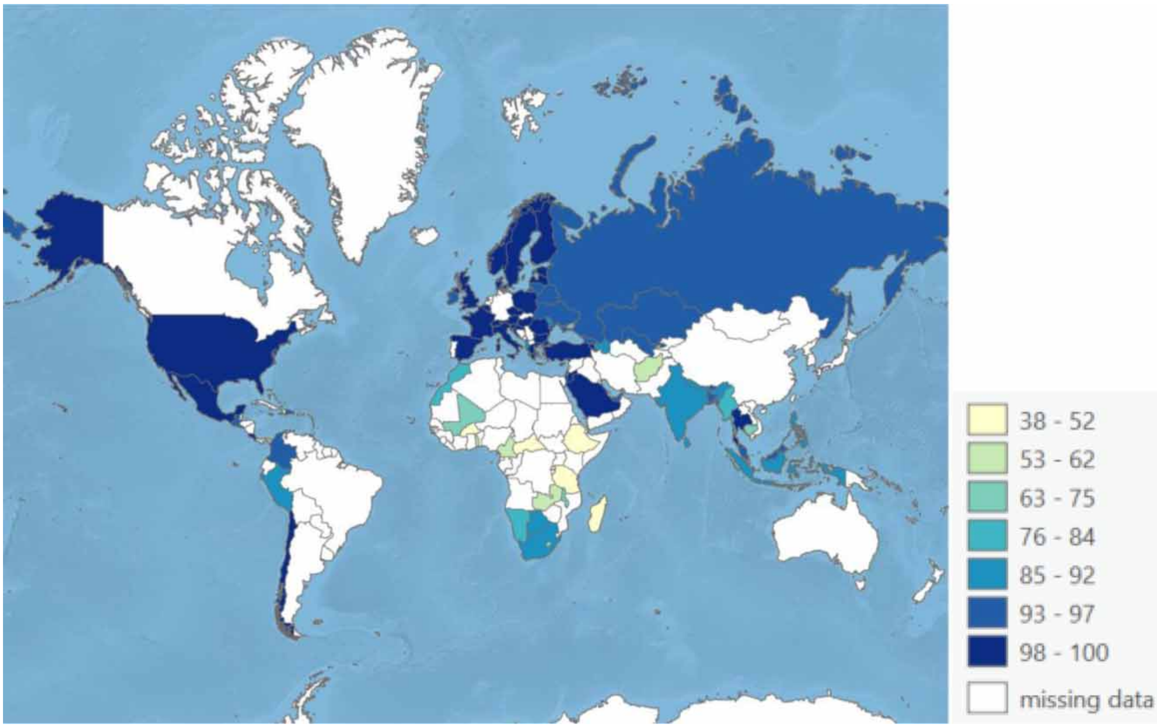
Nearly one-quarter of the world's population lacks effective access to safe drinking water (SDW). The discovery and implementation of affordable and workable measures to supply safe affordable drinking water internationally remains elusive. Few works have examined a range of economic, institutional, and governance factors influencing that access. To address these gaps in the literature, the current study investigates the role of selected economic, demographic, and hydrologic characteristics as well as institutional and governance indicators, all of which could contribute to explaining access to SDW internationally. It estimates regression models based on data from 74 countries for the period 2012–2017. Results contribute to our understanding of factors that are significant at influencing access to SDW. Results show that demographic, economic, size of the public sector, governance, and educational factors all play important roles. Surprisingly, the avoidance of high levels of corruption and the protection of high levels of civil liberties reveal weaker-than-expected effects. Results carry important implications for informing choices facing communities who seek economically affordable measures to provide access to safe affordable drinking water.

**Key words:** Economics, Governance, Policy, Safe drinking water

## HIGHLIGHTS

- Nearly one-third of the world's population lacks affordable access to safe drinking water (SDW).
- Common approaches to discover predictors of improved drinking water have focused on engineering, biological, and technical factors.
- This paper searches for the most important non-technical predictors of access to SDW internationally.
- Findings carry important policy implications

## GRAPHICAL ABSTRACT




# 1. BACKGROUND

## 1.1. Introduction

In 2020, just under three quarters (74%) of the world's population had access to a safe water source (Ritchie & Roser, 2021). Moreover, securing safe drinking water (SDW) may involve a considerable cost in time for people who lack water sources at or near home (Sorenson *et al.*, 2011). People use water for drinking, cleaning, irrigation, manufacturing, cooling, hydroelectric power, and environmental protection and restoration. Access to water is sufficiently important that people will migrate great distances (Niemczynowicz, 1996; Bordalo & Savva-Bordalo, 2007; Islam & Azad, 2008) to ensure access. A person can survive without water for about 3 days (McCally *et al.*, 1998; Arnone & Walling, 2007; Rylander *et al.*, 2013). The body needs water to carry out essential functions, such as balancing internal temperature and keeping cells alive (Heinonen, 2006; Black *et al.*, 2011; Weinthal *et al.*, 2015). Also, acceptable access to safe affordable water is a significant predictor of life expectancy (Clark & Snawder, 2019). Lacking that access leads to elevated levels of infant mortality (Hertz *et al.*, 1994) and childhood diseases (Clasen, 2010).

Overall, access to safe water is a significant element (Hamlin, 2000) of human capital (Pretty & Ward, 2001; Koundouri *et al.*, 2006; Paavola, 2008; Pretty, 2008; Hanjra *et al.*, 2009; McDowell & Hess, 2012; Chant, 2013; Guerrant *et al.*, 2013; Pretty & Bharucha, 2014), carrying considerable implications for economic growth and development (Becker *et al.*, 1990; Barro & Lee, 1993; Borensztein *et al.*, 1998; Glaeser *et al.*, 2004; Acs *et al.*, 2013). Water's relation to human capital is amplified by the growing significance of climate change that elevates the extent and cost of supplying safe affordable drinking water (Sivakumar, 2011). The highest economic valued use of water is for drinking (Erickson & Barnes, 2005; Glied & Neidell, 2010; Willemen *et al.*, 2010; Keeler & Polasky, 2014; Griebler & Avramov, 2015; Gibson *et al.*, 2016; Vermaat *et al.*, 2016). As of late 2017, more than two billion lacked affordable access to SDW (World Health Organization, 2019).

Two kinds of works to date have seen the lion's share of investigations of SDW access analysis. One typically focuses on chemical and biological characteristics of SDW and methods to ensure its supply (Gadgil, 1998). Access to SDW using measures applied in the home like boiling and filtering improve access, but often are not enough alone (Thapar & Sanderson, 2004; Ayoob & Gupta, 2006; Rahman *et al.*, 2009; Cabral, 2010; Zhang *et al.*, 2010; Khan *et al.*, 2013; Wagner & Plewa, 2017) for protection from disease (Sobsey *et al.*, 2008). While most technical, engineering (Gadgil, 1998), and biological causes of poor access to SDW have been well understood for years (Hamlin, 2000), the economic, social, institutional, and policy-related causes (Thapar & Sanderson, 2004; Ayoob & Gupta, 2006; Rahman *et al.*, 2009; Cabral, 2010; Zhang *et al.*, 2010; Khan *et al.*, 2013; Wagner & Plewa, 2017) as well as economically affordable measures to address those causes are still widely debated (Tillman, 2001).

The second type of investigation assesses economic, social, cultural, and policy indicators (Elimelech, 2006). Household size, gender (Gulati, 2010; Oparaocha & Dutta, 2011; Paul *et al.*, 2011; Sorenson *et al.*, 2011; Hall *et al.*, 2014), education (Macpherson, 2005; Hong, 2007; Oswald *et al.*, 2007; Al-Delaimy *et al.*, 2014; Herath *et al.*, 2016), income, and other demographic characters like ethnicity (Dungumaro, 2007) and culture (Meehan *et al.*, 2020) are prime examples (Adams *et al.*, 2016). Other works have found how health and environmental regulations increase access to SDW (Freeman, 2002; Bennear & Olmstead, 2008). Yet another important factor is urbanization (Ehrhardt & Janson, 2011). A 2008 work (Baron, 2008) showed that urban development reduces access to SDW in sub-Saharan Africa (Fotso *et al.*, 2007; Stoler *et al.*, 2012; Rottbeck *et al.*, 2013; Pullan *et al.*, 2014; Schafer *et al.*, 2014; Wang *et al.*, 2014; Fisher *et al.*, 2015; Kumpel *et al.*, 2016; Burt *et al.*, 2017; Emenike *et al.*, 2017). However, the findings do not always agree on which development indicators elevate SDW access. More evidence (McDade & Adair, 2001) found that urbanization has mixed effects on human health. Overall, economic, policy, and institutional analysis has seen less attention in the literature than technical, biological, and engineering works. We know how to supply SDW but are often ignorant on what economic, institutional, and governmental measures make it happen.

Economic analysis has produced some works on impacts of public versus private deliveries of water (Wallsten & Kosec, 2008; Lothrop *et al.*, 2015). Many of these studies investigate the comparative performance of government versus private water supply. Increasing access to SDW needs attention to institutions, for which there are complex interdependencies with economic outcomes (Saleth & Dinar, 2005). Ongoing debate over the role of economic analysis remains important, especially since government organizations take on a primary role for ensuring SDW in most countries (Halpern *et al.*, 2008). Governments typically play three critical roles in water delivery. First, many states view SDW access as something akin to national security (Chilakamarri, 2003). Second, certain water infrastructures like purification plants and conveyance networks can take on the role of a natural monopoly (Hall, 2009; Carvalho *et al.*, 2015; Lombardi *et al.*, 2019), which is important for public policy design. Third, water safety is politically sensitive (Loftus, 2009). These factors support the widespread responsibility taken on by government at various levels for water delivery (Halpern *et al.*, 2008).

Even when the government is not the main supplier, it often controls outcomes through regulatory and policy instruments (Vogelgesang, 1991). In some countries, a government organization may contract with the private sector for the construction and water services. Governments often prescribe drinking water standards (Innes & Cory, 2001). Moreover, most governments take on the role of monitoring water supply and use, and attempt to respond directly or indirectly to water users where there are shortages, low quality levels, or accidents.

Moreover, different regions need different levels of treatment to ensure acceptable safety for drinking. Figure 1 illustrates a world map of SDW for the countries for which we were able to find consistent data.

Access to safe water is an urgent problem in some countries (Patrick *et al*., 2013). A 2008 work (Halpern *et al*., 2008) found that that effective governance characteristics increase the effectiveness of institutions and their capacity to ensure access to SDW. Some authors have discussed the effects of better governance such as lower levels of measured corruption or a better-developed level of democracy as a contributor to higher SDW. These theoretical discussions set up a framework calling for an empirical investigation of government characteristics that provides a higher access to SDW.

### 1.2. Previous work

Several works have investigated choices made by water suppliers on a treatment system when tap water safety is compromised (Doria, 2006). That work found that water suppliers provide a higher water quality when the community's population is larger. A common mitigation of compromised water safety occurs when customers switch from tap water to bottled water. Access to affordable bottled water is a highly valued resource when piped-in water does not exist or is unreliable in service delivery. Some previous works have investigated economic factors of access to SDW as seen in Table 1.

Another factor influencing access to SDW is decentralization (Vasquez *et al*., 2012; Cherunya *et al*., 2015; Garriga *et al*., 2015). Some works have found that decentralization is beneficial for a community because of greater capacity for quicker and more responsive decisions, reduced distances between customers and delivery sources, and an increased need to perform for local customers who spread the word when they discover poor

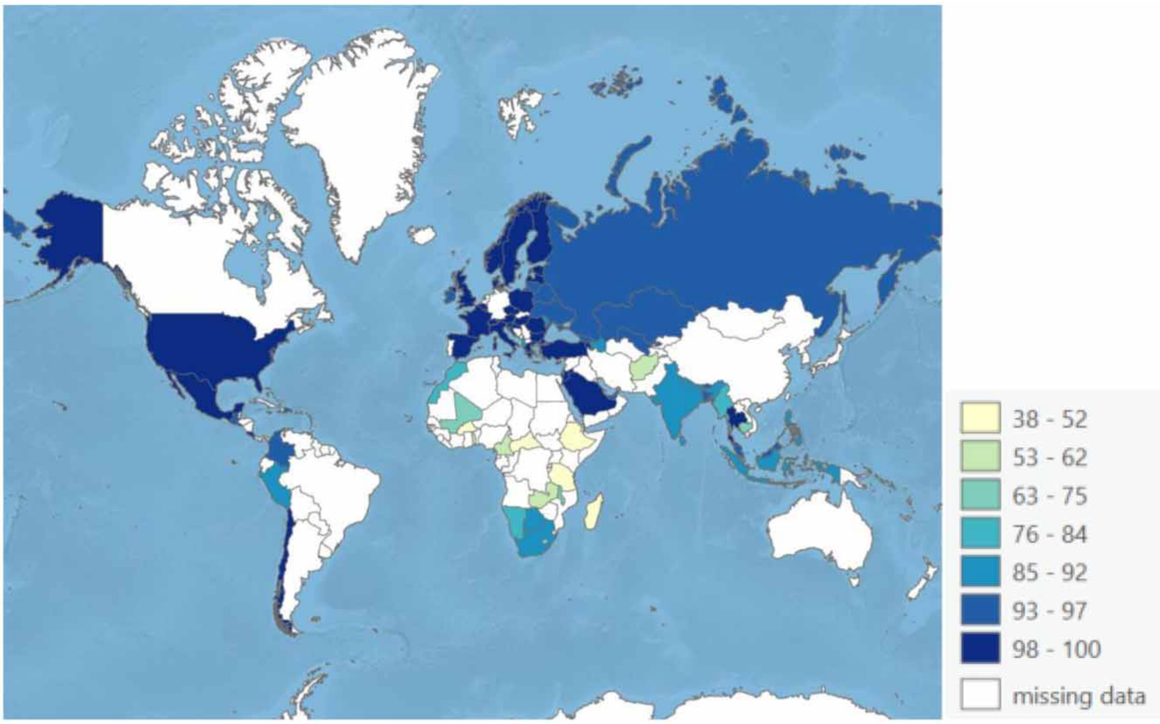



**Fig. 1** | Average percentage population with SDW access (2012–2017).

**Table 1** | Selected significant works addressing access to SDW.

| Author | Year | Themes | Result |
|---|---|---|---|
| Cherunya *et al.* | 2015 | Decentralization | Authors found impacts of decentralized sources in Kenya. |
| Garriga *et al.* | 2015 | Decentralization | Local government can better reveal needs and can classify the process and formulate plans. |
| Vasquez *et al.* | 2012 | Decentralization | Households prefer to secure their water from a centralized provider rather than localized services. |
| Lebek *et al.* | 2021 | Corruption | Corruption leads to a lower level of access to SDW. |
| Povitkina & Bolkvadze | 2019 | Democracy and government role | Democracy has a positive significant effect on SDW. |
| Nketiah-Amponsah *et al.* | 2009 | Income<br>Education<br>Infrastructure | Using safe water depends on income and education. Higher quality water needs reliable infrastructure. |
| Makoni *et al.* | 2004 | Gender and age of head of household | Gender of household significantly affects use of clean water. |
| O'Hara *et al.* | 2008 | Planning for SDW | Well-developed plans are needed to assure access to SDW. |

performance. Decentralized water delivery systems present the advantage of being built in the short term when needed. This reduces the need for a larger-scale investment in centralized wastewater treatment plants carrying a hefty price tag. They also permit the reuse of water at a local scale, which can elevate water's productivity (Larsen *et al.*, 2016).

Some investigations have identified the importance of corruption (Povitkina & Bolkvadze, 2019; Iroegbu *et al.*, 2020; Lebek *et al.*, 2021). One work found that corruption is higher when greater responsibility is assigned for supplying safe water (Asthana, 2008a). Still, regional managers were found to do a better job of ensuring safe water access for residents when there were lower levels of corruption. That kind of investigation implicitly believes that the level of corruption reduces water services for a broader number of families in a community.

One work from Ghana (Nketiah-Amponsah *et al.*, 2009) investigated the social and economic characteristics of drinking water. Their work shows that the safety of piped water is driven by both supply and demand elements. The supply elements depend on the level of infrastructure, and the demand side depends on the resident's income and household head's education. Access to electricity was found to be independent of access to piped water and had a positive relationship with SDW access. Remarkably, gender and age of household head was not found to affect the safety of piped drinking water, although that work investigated the significant role of gender influencing higher priority uses of water (Makoni *et al.*, 2004). Another work investigated the human dimension of water safety (Kot *et al.*, 2015). That work assessed how social health is affected by safe water in Canada, for which results suggest that community readiness is an important contributor to protecting SDW and elevating its access.

A recent study by Povitkina and Bolkvadze (2019) investigates the role of government in the quality of drinking water. They discuss that a positive effect of democracy on water quality depends on the state's role. It is found that more democratic countries with higher responsiveness of government can have better access to SDW. A country with a low level of professional public administration, a weak rule of law, and a high level of corruption has a lower level of SDW access.

The journal *Water Policy* has published a number of important works on economic, social, health, and quality-of-life factors that are related to access to SDW (O'Hara *et al*., 2008; McKenzie & Ray, 2009; Vasquez, 2011; Ching, 2015; Gurung *et al*., 2019). Work conducted in Kazakhstan shows that having an affordable plan with an accurate explanation of goal definitions is helping legislators in different ways: first, it provides a clear target; second, it makes the monitoring practical; and finally, it makes the plan more acceptable for the governments (O'Hara *et al*., 2008). Carefully designed and executed water policies are essential for meeting the needs of water in urban areas (McKenzie & Ray, 2009). Having a market system with minimal control by government cannot on its own solve the SDW problem when the community faces significant challenges with reliable data. Those who have travelled extensively in the global south will recognize this as a common problem. Moreover, weak access to SDW was found in Guatemala to occur not only because of water infrastructure, but also the social norms and institutions are not adequate to increase SDW (Vasquez, 2011). Several notable works from other journals addressed challenges facing efforts to develop safe water (Naiga *et al*., 2015), demand predictors for SDW (Baguma *et al*., 2013), impacts on family health from improved access (Baguma *et al*., 2013), health challenges posed by water fetching (Venkataramanan *et al*., 2020), and effect of SDW on health and human capital (Bisung & Elliott, 2016). Some of the more important previous works are presented in Table 1.

### 1.3. Gaps and objectives

Previous works have hypothesized that certain characteristics like corruption levels, government effectiveness, and extent of civil liberties (Torras & Boyce, 1998; York *et al*., 2003), defined as guarantees and freedom governments cannot abridge, all affect SDW access. However, information on the role of improved governance to support access to SDW presents a difficult challenge for analysis, with few easy answers to date. A carefully executed statistical analysis assessing impacts on SDW access influenced by economic indicators, corruption levels, governance characteristics, demographic, and hydrologic characteristics would be a welcome contribution to the literature (Mondiale, 2008; Halpern *et al*., 2009). To address some of these gaps in the literature, the current study investigates the role of selected economic, demographic, and hydrologic characteristics as well as institutional and governance indicators, all of which could contribute to explaining access to SDW internationally.

## 2. METHODS OF ANALYSIS

We began our investigation by looking for good data. To achieve this, we used data secured from 74 countries for the period 2012–2017, for which those data were used to estimate a regression model predicting access to SDW for those countries and years. Economic, geographic, cultural, hydrologic, and governance factors that could influence SDW were investigated. We secured data from several sources to build a consistent and complete dataset.

### 2.1. Data

#### 2.1.1. Safe drinking water access

Several organizations track access to SDW. The World Bank annually reports on this in its Development Indicators (World Bank, 2022). One common measure of access to SDW is the percentage of the population that consumes water from a safely managed drinkable water source. The Bank defines SDW access by the percentage of the community's population using an improved drinking water source. That water source can include piped household water connection located inside the user's place of dwelling or their plot or their yard, as well as other improved drinking water sources such as public taps or standpipes, or tube wells/boreholes, protected hand-dug wells, as well as protected springs, or collected rainwater facilities. Economic benefits provided by improved access to drinking water include things like elevated economic productivity, elevated education, and savings in costs of health care. Another excellent program is the Joint Monitoring Program of WHO and UNICEF, an important drinking water and sanitation monitoring program that supplies information to permit making comparisons among countries and over periods of time (WHO/UNICEF Joint Water Supply Sanitation Monitoring Programme, 2015).

While challenged by well-known limitations, the World Bank index we used is assembled by the Bank to be consistent throughout countries for which it has data. Our study constructed a database with that variable for 74 countries for which we were able to secure the complete dataset on all variables predicting access to SDW (Figure 1). For anybody who has travelled widely, access to SDW worldwide sees quite a range. Ethiopia has the lowest access, for which only 38% of the population has it. At the other end, 100% of the population has access to SDW for nine countries in that dataset: Malta, Kuwait, Bahrain, Denmark, Germany, Romania, Greece, Austria, and Israel. Some of these countries have invested large sums of money as well as planning and political capital over a long period of time since the 1940 s to ensure this access, for which that SDW access has produced hard won gains over many years (Hrudey & Hrudey, 2004).

Some European countries such as France, Hungary, and Estonia show an index higher than 98% but lower than 100%. For our dataset, the average percentage of the community population with weak SDW access, overall years and countries, is 70%. Most are poor, with an average daily income less than US $2.00. Still, poverty does not itself explain weak access to SDW. Different nations, even some with high per capita incomes, face this problem. Indeed, the 2 billion lacking access to SDW are scattered throughout rich as well as poor countries.

#### 2.1.2. Per capita gross domestic product

We expected that a higher per capita gross domestic product (GDP) would reveal better access to SDW for several reasons. Rich countries have more financial resources to build purification infrastructure and implement financially sustainable bill collection methods. As individual incomes rise, there are more opportunities for finding SDW, including home water filters, purchased bottled water, and affordable energy when boiling is required (Whelton *et al.*, 2007; Ahmad & Bajahlan, 2009; Vasquez *et al.*, 2009; Loo *et al.*, 2012; Bain *et al.*, 2014). Figure 2 shows the range of per capita GDP internationally in countries for which our data were available and consistent.

#### 2.1.3. Gini coefficient

GDP per capita can be a good proxy for a nation's average economic performance, but it says little about its distribution. The Gini coefficient index (Taylor & Short, 2009; Plummer *et al.*, 2010; Panuwet *et al.*, 2012; Rasul, 2014; Valle *et al.*, 2015; Hartmann *et al.*, 2018) measures statistical dispersion of income or wealth within a community. It indicates the extent to which members of the community face unequal access to resources. This index is reported in World Bank data for all of our countries used, for which a higher coefficient indicates less equality (Luh & Bartram, 2016; Chaudhuri & Roy, 2017; Guragai *et al.*, 2017; He *et al.*, 2018; Malakar *et al.*, 2018). Our expectation was that a higher Gini coefficient (greater income and wealth inequality) would lead to reduced measured access to SDW.

#### 2.1.4. Education

Education level was anticipated to be another important economic factor explaining access to SDW. People with higher education possess greater levels of human capital and have a better-developed understanding of the importance of access to SDW to their health and welfare. The better educated are often the first to leave a country when SDW access declines, leading to out-migration. The current study considers a secondary education completion rate, which is measured as the percentage of population with at least a high school diploma. It was expected that a higher percentage of education, measured in this way, would increase the demand for SDW (Hong &

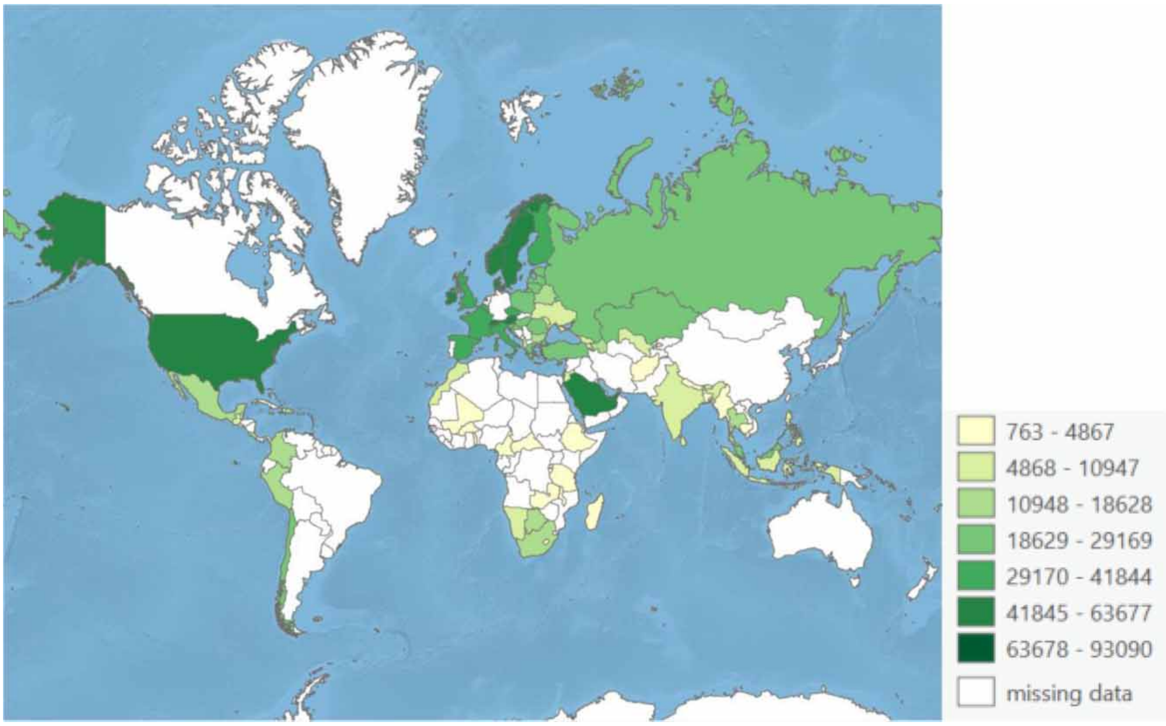



**Fig. 2** | Average per capita GDP (2012–2017).

Mishra, 2006; Chatterjee *et al.*, 2017; Eghtesad *et al.*, 2017). Figure 3 presents that level of education internationally for our dataset.

### 2.1.5. Corruption avoidance

The problem of corruption and what to do about it has taken on growing importance since the early 2000s (Robertson & Watson, 2004; Sanyal, 2005). There has been a considerable growth in scientific research on corruption, but attention from the news media has brought to light events like corruption scandals. Additionally, governments, various financial institutions, as well as NGOs have put increasing resources into fighting corruption. The corruption avoidance perception index (CAPI) is an indicator developed in recent years by Transparency International for which a higher numerical value indicates more transparency.

Higher corruption can be an important obstacle that blocks community access to SDW (Asthana, 2008b; Anbarci *et al.*, 2009; Pagano *et al.*, 2014; Gomez *et al.*, 2019; Herrera, 2019; Sinharoy *et al.*, 2019). The CAPI is used in our model to test the effect of greater transparency (reduced corruption) on access to SDW. The CAPI was only available to us for the years 2012 and later, an important reason for our study limiting its years of analysis from 2012 to 2017. Figure 4 shows the CAPI for our countries. We expected that a higher CAPI would increase access to SDW.

### 2.1.6. Government scale

In addition to the availability of resources to build needed infrastructure for safe water, we considered the scale of government, measured as the percentage of government expenditure making up GDP. This index explains the absolute scale of the government sector. While a greater scale of government may reduce SDW access by

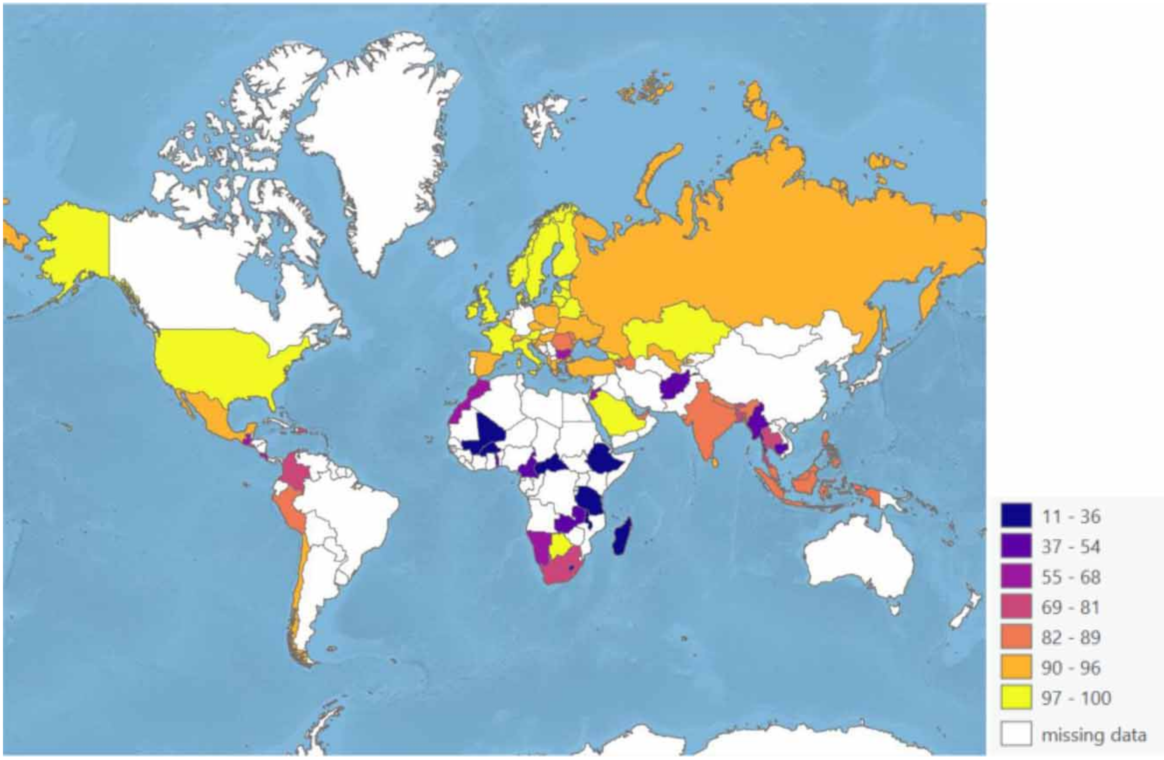



**Fig. 3** | Average percentage population with at least secondary education (2012–2017).

blocking private sector innovations in water supply development or delivery systems, a higher scale could also increase SDW access by providing a greater government oversight over non-performing elements of the private sector water supply system. So, access to SDW could be higher or lower within countries with a higher absolute scale of government activity.

### 2.1.7. Government effectiveness

The last group of indices tested to investigate impacts on access to SDW were various proxies for governance. This group includes the level of government effectiveness, transparency (corruption avoidance), and extent of civil liberties. Better governance leads to better management of public services (Bordalo & Savva-Bordalo, 2007; Gupta & Lebel, 2010; Dupont *et al*., 2014; Kayser *et al*., 2015).

Government effectiveness is one of many elements of governance (The World Bank, 2021). The Bank's indicators project presents total as well as individual governance indicators for more than 200 countries for the years 1996–2020 for the following six proxies for governance: absence of terrorism and violence, voice and accountability, government effectiveness, political stability, rule of law, regulatory quality, and capacity to control corruption (The World Bank, 2021). The range of this indicator is −2.5 to 2.5. The level of government effectiveness internationally is shown in Figure 5 as summarized in Appendix C. Water governance presents complex territory for analysis, as described in many recent works (Huitema *et al*., 2009; Pahl-Wostl, 2009; Engle & Lemos, 2010; Pahl-Wostl *et al*., 2010, 2012; Cook & Bakker, 2012; Huntjens *et al*., 2012; Linton & Budds,

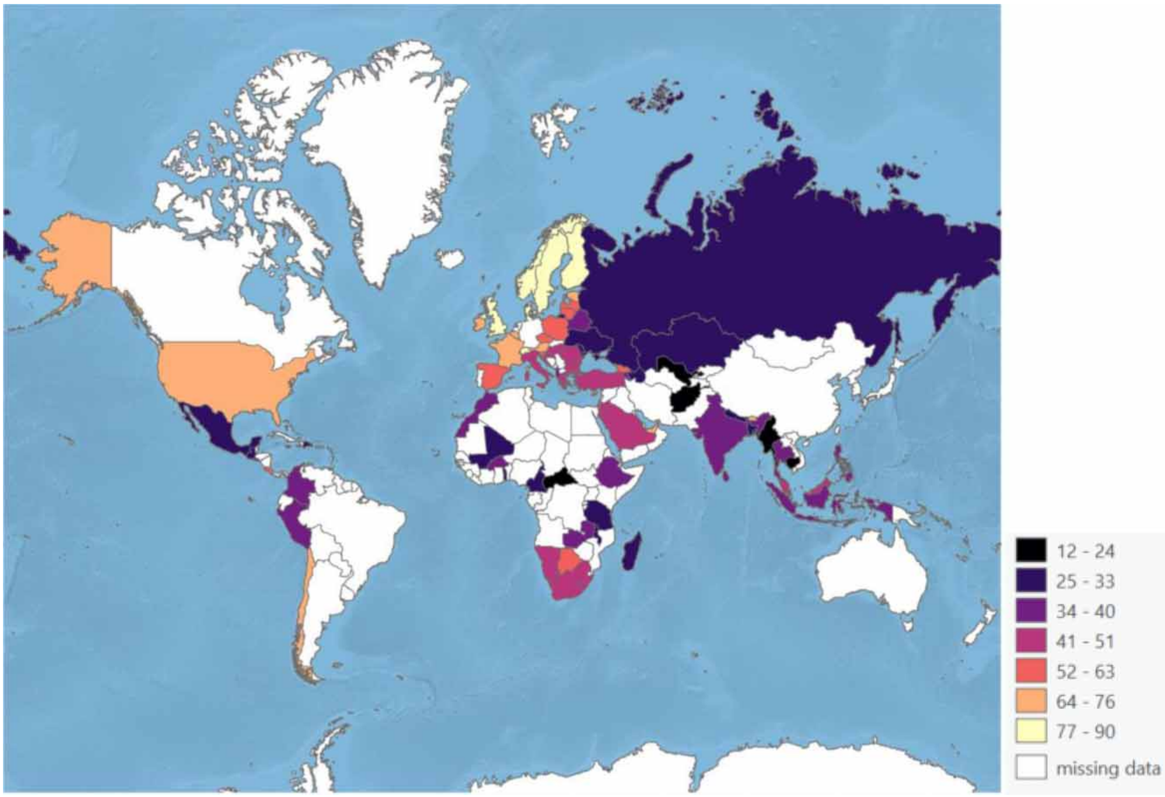



**Fig. 4** | Average level of corruption avoidance (2012–2017).

2014). Measuring government effectiveness is a complex and multi-layered task. Governance as well as incentives, ownership, professionalism, and other elements also matter and are part of government effectiveness.

### 2.1.8. Civil liberties

Civil liberties (Nelson *et al.*, 1997; Li *et al.*, 1998; Torras & Boyce, 1998; Vanhanen, 2000; York *et al.*, 2003; Davis & Silver, 2004), for which we used a measure provided by Freedom House, was defined as the degree of freedom for expression and belief, having right of associations and organizations, rule of law, and personal autonomy and individual rights. While not measured with scientific instruments of the sort used to measure various water quality elements, it was the best consistently measured data we could find. The indicator's range is from 1 to 7. A higher level reflects lower levels of liberty for its citizens. This index is shown in Figure 6.

Freedom House has another index for indicating democracy, namely political rights. This index has a high collinearity with civil liberties, which means a near-linear relationship between the two, giving rise to the classical problem by which it is difficult to disentangle partial impacts on the dependent variable of the two linearly related variables (Graham, 2003; Dormann *et al.*, 2013). Facing that high collinearity in a regression leads to low *t*-statistics in some of the collinear explanatory variables even though collinearity by itself does not lead to biased parameter estimates (Farrar & Glauber, 1967; Rosipal & Trejo, 2002; Graham, 2003; Chong & Jun, 2005; Chun & Keles, 2010). For this work, the index of civil liberty is viewed as an index characterizing individual freedoms.

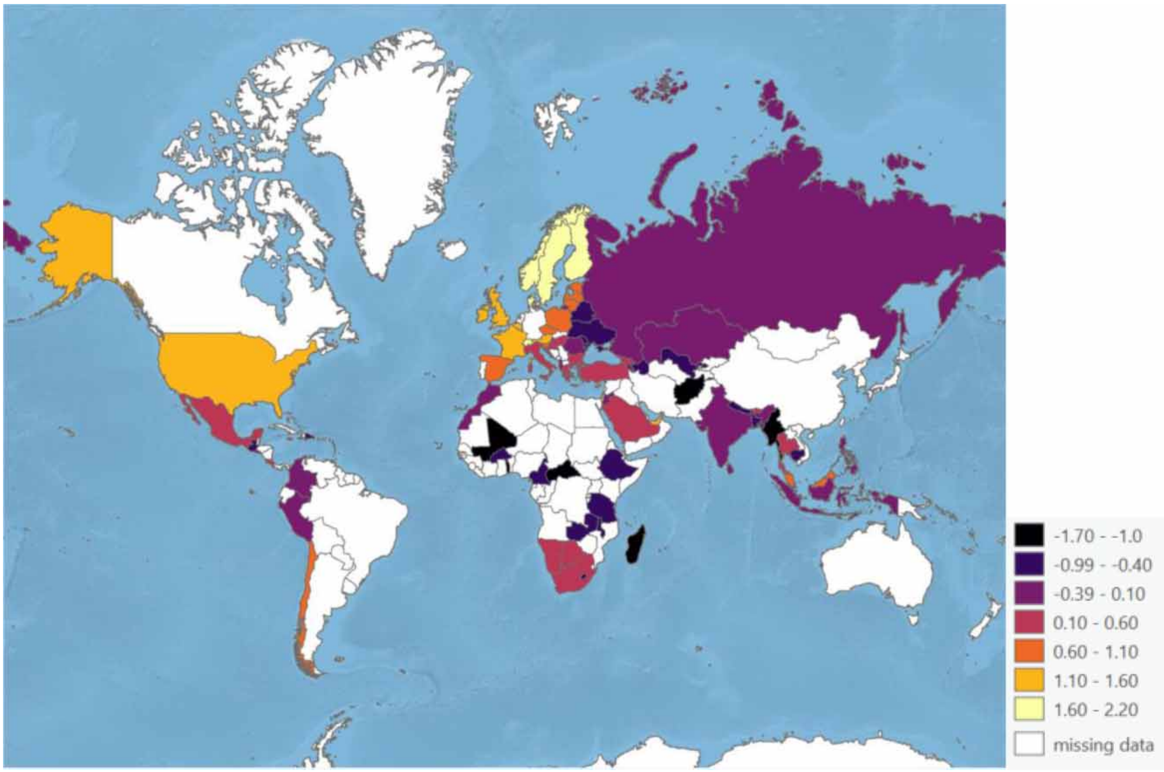



**Fig. 5** | Average level of government effectiveness (2012–2017).

### 2.2. Summary of variables measured

The dependent and several explanatory variables described above are defined in Table 2. A few of their simple statistical summary characteristics are included.

### 2.3. Model

Numerous factors presented themselves as potential variables that could explain the variation in SDW seen over our countries and years. Overall, SDW depends on the social, economic, geographic, political, and hydrologic conditions of a country. Equation (1) expresses this relationship conceptually:

$$\text{Access to SDW} = f(\text{social indicators, economic indicators, Gini coefficient, geographical indicator, scale of government}) \quad (1)$$

That is, effective access to SDW is expected to be a function of various indicators of a community's economic performance, social characters, geography, hydrologic characteristics, and its structure of government.

The model below is specified to translate this theoretical principle into one suitable for estimation and policy assessment. Equation (2) summarizes the model:

$$SDW_{it} = \beta_0 + \beta_1 PCGDP_{it} + \beta_2 Gini_{it} + \beta_3 GS_{it} + \beta_4 Ed_{it} + \beta_5 GE_{it} + \beta_6 CAPI_{it} + \beta_7 CIL_{it} + \varepsilon_{it} \quad (2)$$

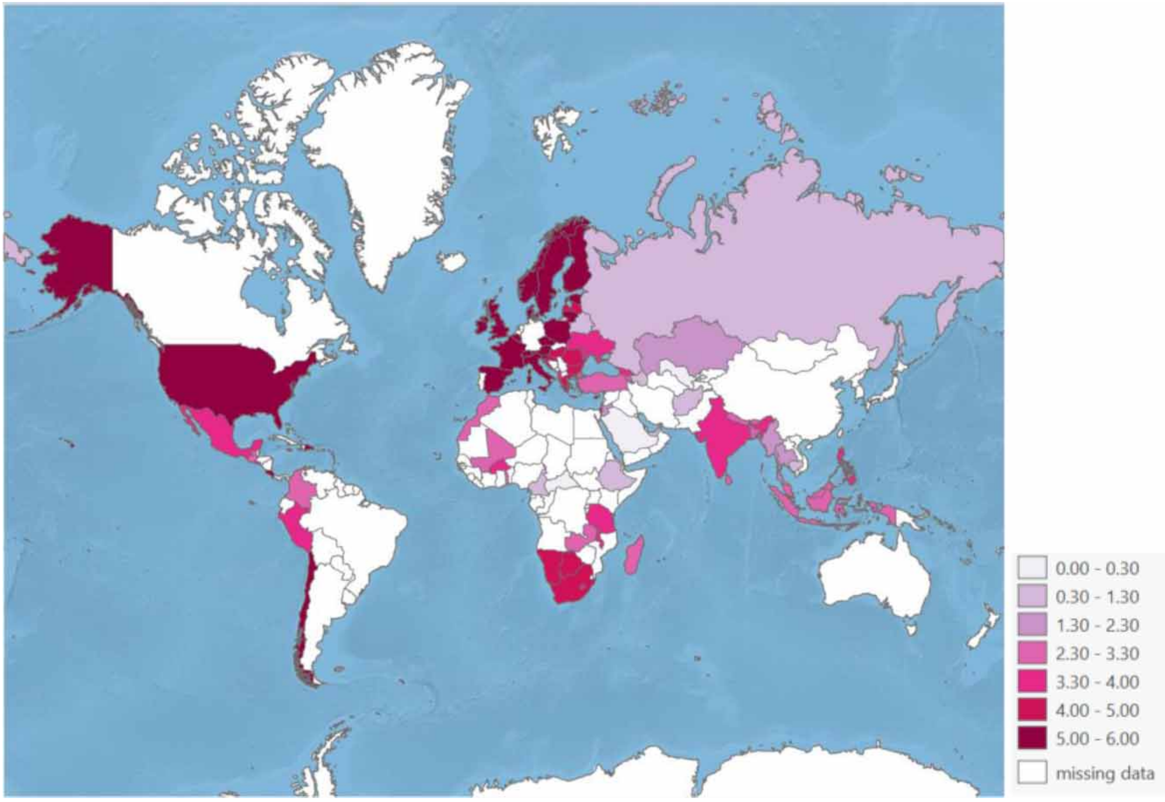



**Fig. 6** | Average level of civil liberties (2012–2017).

**Table 2** | Explaining access to SDW: summary statistics.

| Variable | Units | Observations | Mean | SD | Min | Max |
|---|---|---|---|---|---|---|
| Per capita GDP | $US 2018 | 305 | 26,276 | 17,994 | 1,140 | 96,286 |
| Gini | Index (0–100) | 305 | 34.90 | 7.11 | 24 | 63 |
| Education HS or more | Percentage (0–100) | 305 | 89.46 | 14.49 | 24.73 | 100 |
| Corruption avoidance | Index (0–100)[a] | 305 | 52.99 | 19.03 | 22 | 92 |
| Government size | Percentage of GDP (0–100) | 305 | 30.29 | 10.52 | 4.01 | 59.9 |
| Government effectiveness | Index (−2.5 to +2.5)[b] | 305 | 0.59 | 0.84 | −1.24 | 2.22 |
| Civil liberties | Index (1 to +7)[c] | 305 | 4.67 | 1.54 | 1 | 6 |

[a]Available from Transparency International. A higher number shows less corruption (https://www.transparency.org/en/cpi/2017/index/nzl).
[b]Available from IMF and reported by World Bank (https://data.worldbank.org/indicator/GC.XPN.TOTL.GD.ZS?view=chart).
[c]Available from Freedom House (https://freedomhouse.org/report/freedom-world). The index is calculated by authors for an easier interpretation.

where *SDW* is the percentage of the population with access to SDW, *PCGDP* is per capita GDP, *Gini* is the Gini index, *GS* is government size, and *Ed* is the average level of education. The term *GE* is a governmental structure indicator, government effectiveness. The *CAPI* reflects higher control over corruption, i.e. greater transparency.

Finally, the extent of civil liberty appears as *CIL*. The term $\varepsilon$ is the error, the $i$ index refers to the $i$-th country (cross-section), while the $t$ index is the $t$-th year, running annually from 2012 to 2017. Equation (2) was estimated in the linear form above as well as in the log–log form in which natural logs are taken for the dependent variable and all independent variables. For the log–log form, estimated coefficients are interpreted as direct elasticities, i.e. the percentage change in the dependent variable from a one percent change in the independent variable.

### 2.4. Estimation

We used panel data to estimate the statistically significant variables to predict effective access to SDW. We include various government structure and performance variables to test the role of the state in providing SDW. The dataset was robust, initially covering 86 countries over the years 2012–2017, but was reduced to 74 when including the Gini coefficient of income inequality as a predictor, since not all 86 countries had data on that term. We conducted homoscedasticity, multicollinearity, and Hausman and Pearson tests, for which those definitions appear in Appendix A. Based on their results, a fixed-effect panel data regression analysis was estimated, for which results are shown below in Table 3. That table shows summary statistics of the 305 usable observations used for our 74 countries and 6 years. Not all variables were available for all years and all countries.

## 3. RESULTS

### 3.1. Overview

Our findings reveal several overarching points:

- *Per capita GDP*: Access to SDW sees significant elevation in those countries that have a higher level of income as shown in both the linear and log–log model estimation results shown in Table 3. Higher per capita GDP significantly increases SDW access for many reasons, including greater access to technology, a greater ability to pay for SDW, and a higher access to effective transportation networks to secure SDW.

**Table 3** | Model results – predictors of access to SDW.

**Dependent variable: percent of population with SDW access**

| | Model I (Linear) | | | Model II (Cobb-Douglas) | | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | ***t*-value** | ***p*-Value** | **Coefficient** | ***t*-value** | ***p*-Value** |
| Intercept | 61.02*** | 25.73 | <0.0001 | 28.219*** | 32.23 | <0.0001 |
| Per capita GDP | 0.00009*** | 3.88 | 0.0001 | 0.085*** | 11.12 | <0.0001 |
| Gini | −0.102*** | −3.04 | 0.0026 | −0.004 | −0.31 | 0.75 |
| Education HS or more | 0.035*** | 3.16 | 0.0018 | 0.044*** | 5.12 | <0.0001 |
| Corruption avoidance | 0.009 | 0.54 | 0.589 | −0.0003 | −0.04 | 0.97 |
| Government size | 0.054*** | 2.68 | 0.008 | 0.039*** | 6.47 | <0.0001 |
| Government effectiveness | 0.422* | 1.18 | 0.239 | 0.017* | 1.37 | 0.17 |
| Civil liberties | −0.0186 | −0.12 | 0.901 | 0.009** | 2.27 | 0.02 |
| Number of cross-sections (countries) | 73 | | | 73 | | |
| Adjusted $R^2$ | 0.99 | | | 0.45 | | |

***99 percent significance level.
**95 percent significance level.
*90 percent significance level.

- *Inequality*: A higher Gini index, greater inequality, leads to reduced SDW, shown in both functional forms used. Those who live in a country with more equality have better access to SDW. This point was brought out clearly in a work on water inequality in the United States, in which the authors found that greater inequalities in income levels, median age, and rural remoteness reduced effective access to SDW (Mueller & Gasteyer, 2021)
- *Education*: Education matters. Communities with a higher percentage of its citizens achieving at least secondary education use that education to demand, supply, or secure greater access to SDW.
- *Government size*: The scale of government matters. The absolute scale occupied by government as a proportion of GDP has a significant influence on access to SDW, partly because a greater scale gives rise to a greater capacity to regulate, require, or enforce a greater access to SDW.
- *Government effectiveness*: Nations with high levels of government effectiveness show higher access to SDW, but the statistical results are marginal for both the linear and log–log form.
- *Civil liberties*: Unexpectedly, countries with higher levels of civil liberties do not show a significant effect on SDW for the linear model but do show an effect for the (Cobb-Douglas) log–log model. Civil liberties may already be picked up in government effectiveness.
- *Corruption avoidance*: Effects of government transparency (corruption avoidance) are only weakly supported for both model forms used.
- *Non-predictors*: Several factors were surprisingly weak predictors of access to SDW. Some of these included various geographical indicators, such as natural water supply per capita, and numerous physical climate characteristics. This tells us that where the system of government, economic productivity, and education levels are top performers, measures will be put into place to secure SDW access, despite geographic or meteorological factors making it more difficult.

## 3.2. Detailed findings

Table 3 shows detailed results of the estimated model. The first column names the independent variables. The next column shows estimated regression coefficients for each predictor variable, while the third and fourth columns show statistical significance of the coefficients. The first model (Model I) includes the linear form, while the second model (Model II) uses the log–log functional form. Coefficients for the log–log form are elasticities, namely the percentage change in the dependent variable from a one percent increase in the independent variable.

### 3.2.1. Per capita GDP

A country's GDP measures the monetary market value of all the final goods and services supplied per year. The ratio of GDP to the total size of population of the community is per capita GDP, which amounts to the country's mean standard of living. Economic welfare has been measured with many metrics for water resource assessments (Beckerman, 1992; McConnell & Rosado, 2000; Ward & Pulido-Velazquez, 2008). Our choice of economic welfare was per capita GDP partly because of its extensive availability. The estimated effect in Table 3 shows that a one percent increase in per capita GDP gives rise to about an 8.5 percent increase in SDW access for any of the countries analyzed for this work. So, the effect is numerically small, but important. Increasing per capita GDP may work but is likely a much more expensive method to increase access to SDW than some of the other measures considered.

GDP (income) matters because other infrastructure needs are able to be addressed as per capita income rises. Water is life, but so are hospitals, schools, roads, as well as access to affordable energy, food, and telecommunications. This work does not directly address private investment in water systems including funding by way of issuing bonds. Yet access to international capital markets also matters. High incomes are likely correlated with this external driver.

### 3.2.2. Gini coefficient

For this work, the Gini coefficient, which ranges from 0 to 100, measures the statistical dispersion or variability of income within a community (Gini, 1936). A community with a higher Gini coefficient has a larger inequality in income distribution. A community with a zero Gini coefficient expresses perfect equality of income among all community members, while a community with a coefficient of 100 has maximum inequality among people, for which one individual has all the community's income and the others have none. Our expectation was that higher inequality of income would reduce the proportion of the overall population with SDW access, reflecting the finding that a more unequal distribution of a community's income produces a larger proportion of the population living in the margins of influence and less likely to have access to SDW. Gini coefficient data for our work are shown in more detail in Appendix C, with values ranging from 24 to 63. The linear model is consistent with our prior expectation and a higher Gini coefficient shows a one unit increase in the coefficient producing a 0.10 unit decrease in SDW, but this effect is not statistically confirmed in the nonlinear model although the sign is negative as expected.

### 3.2.3. Size of government

The estimated coefficient on government spending as a percentage of GDP (government size) shows a significant increase in SDW with higher levels of that spending. A one percent increase in the proportion of government spending making up GDP leads to about a .04 percent elevation of SDW, with similar results for the linear and nonlinear models, both significant at the one percent level. It would have been desirable to find data showing the proportion of GDP spent on SDW delivered, as it would have likely had a much stronger impact, but no such data were available to us.

### 3.2.4. Education levels

Education levels show a statistically significant and positive relationship with SDW. This finding is evident across our 74 countries and 6 years' data. Comparing the two models here did not change this result much. Indeed, education is an important predictor of access to SDW in both models. A one percent increase in the percentage of high school or more education leads to .04 percent elevation of SDW for the log-log model. It is highly significant for both models. People with greater education are taught to assign a higher safety and health value to SDW and, through personal choices in selected political leaders and a place to live, have a greater effective demand for it (Gulati, 2010; Perez-Vidal *et al*., 2016; Chatterjee *et al*., 2017).

### 3.2.5. Structure of government

*3.2.5.1. Government effectiveness*. A more efficient government numerically increases access to SDW, but the significant level of this variable is a marginal, showing a 0.23 probability in the linear model that this variable actually has no impact on SDW, with similar results in the nonlinear model. Results of the table show that a one unit increase in government effectiveness leads to a 0.42 unit increase of SDW for Model I with an elasticity of 0.017 for Model II.

*3.2.5.2. Corruption avoidance*. Corruption perception is an important characteristic of a community's governance. A higher corruption avoidance index shows greater transparency. It has been found by other works that corruption is a negative attribute of a state, and it undermines a community's economic performance (Drury *et al*., 2006). Economic theory suggests a negative effect of corruption on SDW (Mondiale, 2008). On the other hand, some studies have found that corruption in some communities reduces the complexity of the economy (Cummins & Gillanders, 2020). Remarkably, our current study results do not show a statistically significant effect of corruption avoidance on SDW for the linear and nonlinear models. This is a difficult finding to explain, because it would seem that a less corrupt government would give rise to better performance in ensuring SDW access (Johnson *et al.*, 2014). We treat this finding with caution and would like to see more extensive research investigating these results.

*3.2.5.3. Civil liberties*. Countries with higher civil liberties measured by our database show a statistically significant relationship to SDW access in a nonlinear model. The coefficient effect −0.0186 for Model I with a weak performance, but changes sign and is statistically significant in a level of 2 percent in Model II. We expected that a community with greater civil liberties would show a much higher access to SDW, which was indeed found for the log–log model.

#### 3.2.6. Insignificant SDW predictors

No measure of greater political stability that we could find produced a statistically detectible relationship that influenced SDW. For example, our findings could not confirm the level of political rights as a significant predictor of access to SDW. Measured internal physical freshwater per capita was investigated with one preliminary regression (not shown), but never came up as a statistically strong predictor of SDW access. Data on that variable were only available from 2012 to 2014 in the World Bank dataset to which we had access, so it is possible that a more complete database on freshwater per capita would show more interesting results. In addition, we tested for impacts of seven continental aggregations of countries. These aggregations include North America, Asia, The Middle East, The Far East, sub-Saharan Africa, Central American, and South America. None of those aggregations entered the model with acceptable statistical significance.

### 3.3. Policy implications

Water is an essential factor in human health, productivity, and economic welfare. Many research works have investigated different technical, engineering, and biological factors influencing SDW access. Few have looked at non-technical contributors to SDW. The current study attempts to address this gap in the literature and, in so doing, uncovered some results that carry policy implications. Government contributes a large percentage of water supply in most countries. Still, its effectiveness measured in our World Bank dataset does not show a significant effect on SDW. In addition, the levels of education, government size, per capita GDP, and equality increase SDW. These factors are important contributors to provide SDW for a country regardless of geographical or climate condition. The anticipated strong effect of other factors like corruption and political stability were not borne out by the results. However, civil liberties can affect SDW, although without as much strength as the other variables.

## 4. DISCUSSION

### 4.1. Significance

This study has investigated a range of factors to predict access to SDW at the national level. Two groups of social–economic and government variables are good predictors of access to SDW. Per capita national income shows the nation's capacity to support SDW. The Gini coefficient shows the degree of inequality in a country. A higher per capita GDP with a lower Gini coefficient (higher equality) leads to higher SDW. These results square with prior expectations.

Another variable in the group of social–economic factors is the absolute scale of government. Government is the main provider of safe water provider worldwide, and it is important to consider its size and capacity to pay for water utilities' construction. Several variables such as total government spending, government spending as a percentage of GDP, and per capita government spending were all assessed in the estimation. The best one was found to be government size with the definition of government spending as a percentage of GDP. A larger sized government covers a higher percentage of community members with SDW. For this reason, this positive significant relationship accords with prior expectations.

Education is an important social–economic variable for predicting access to SDW. The educated are more aware of the importance of SDW to their health and economic welfare. The demand for safe water in this group is higher than in the less educated. The data of percentage of population over 25 years old with high school-level education are used to predict SDW access. This variable is strongly related to SDW. Both regression models presented confirm the positive significant effect on access to SDW. Surprisingly, geographical indicators are weaker-than-expected predictors of SDW.

Government characteristics like government effectiveness and corruption effects on SDW are not statistically discernable, while civil liberty has an effect on SDW based on a nonlinear model. This work is one of the few that has empirically sought and discovered social, economic, and institutional factors predicting access to SDW. Despite the contributions of this work, it has limitations, some of which are discussed below.

## 4.2. Originality

Previous works have investigated that numerous characteristics such as corruption levels, various indications of government performance, and measurable extent of civil liberties seen as freedom governments cannot abridge. However, despite numerous excellent works, factual findings on the role of the improved performance of governance to support access to SDW have presented a difficult challenge for analysis, with few water-tight answers to date. Other studies have attempted to identify key elements affecting water sector performance, including SDW. Many efficiency studies have been conducted – considerably more than cross-country works. In that light, access to SDW is either understudied or factors affecting SDW are contextual, determining SDW in nonlinear ways such as was presented in Model II above.

A well-documented and professionally performed statistical analysis assessing impacts on SDW access influenced by numerous economic indicators, corruption levels, governance characteristics, demographic, and hydrologic characteristics is a welcome contribution to the literature (Saleth & Dinar, 2005; Mondiale, 2008; Halpern *et al.*, 2009). This work has performed a new investigation of the role of various economic, demographic, and hydrologic characteristics as well as institutional and governance indicators, all of which could contribute to explaining access to SDW internationally.

## 4.3. Limitations

This work is one of the few empirical investigations on the effect of government effectiveness on providing SDW. Statistical investigation explaining different factors of access to SDW needs much more attention in future work. While our results partly matched prior expectations, not all expectations were borne out. A larger dataset, more predictors, data from more countries or from a longer time period, or various innovative nonlinear functional forms could all shed light on the problem we assessed.

One challenge facing the current study has been to assemble geographic indicators that are consistent across countries. The geography of any one country is rarely homogenous, so averaging presents the classical well-known problems. Some parts of a single country can be drier, wetter, higher, more mountainous, or more humid than others. This presents a bigger problem in larger countries. Finding a scale at which to define a country's unique geographic character is difficult without some insightful weighting schemes rarely tried to date. The authors of the current study tried to use the variable of per capita internal fresh water published by the World

Bank to show aridity of a country, but this indicator was not readily available after the year 2014. Limitations of geographical indicators are another challenge of this study that needs to see future advances.

Many of the limitations of this work come from the limitations of the measured variables themselves, all of which are highly aggregated and are not set up to be experimentally varied, one variable at a time, while watching the outcome of access to SDW. So, many of these limitations can only be overcome in future years when more consistently collected data are desired, developed, and implemented, which is a costly enterprise.

### 4.4. Future work needed

The current study makes an incremental contribution to understanding factors influencing access to SDW. Future works are needed to move these findings forward. Ours is one of the few efforts for which various elements of governance are statistically tested for their effect on providing SDW. Future work may uncover more information on other social, economic, geographical, institutional, and community structural characteristics that lead to higher SDW.

More data, especially those that are consistently collected, would be a resource of immense value. While our dataset was large (Appendix C), it has limitations. Future studies are needed to learn more about the role of education in contributing to SDW. If an index can be developed that shows the percentage of literacy, especially scientific literacy (Laugksch, 2000; Norris & Phillips, 2003; Bonney *et al.*, 2009), that index would reflect the percentage of population with capacity to understand and, in some cases, write new scientific material for mass consumption. Access to more information improves the individual's capacity to participate more effectively in water governance. So, a literacy index, more consistently collected, may provide a better way to explain SDW than we were able to assess. Data summarizing effective literacy rates are missing for many countries, forcing this study to use a much simpler proxy for literacy.

In light of all the elements discovered in this work that can succeed in increasing access to SDW, future work is needed to formulate and apply optimization models to find the least cost set of elements to increase SDW from current levels to higher desired levels (Hsu & Cheng, 2002; Draper *et al.*, 2003; Xevi & Khan, 2005; Pulido-Velazquez *et al.*, 2006; Momtahen & Dariane, 2007; Cai, 2008). Optimization exercises could reduce the cost of achieving a given desired level of SDW access. Their use can also raise the level of SDW access achievable with existing capacity expansion resources. Many measures work in the technical sense, but only a few pay in the economic sense. There is a need to use optimization models to uncover least cost sets of measures using our coefficients or similar ones from other works to ensure SDW in places where it is most needed when SDW measures are expensive or scarce.

Many examples of optimization models have been developed in recent years for addressing water management challenges (Wurbs, 1993; Draper *et al.*, 2003; Labadie, 2004; Kuby *et al.*, 2005; Xevi & Khan, 2005; Pulido-Velazquez *et al.*, 2006; Cai, 2008; Ostfeld *et al.*, 2008; Maringanti *et al.*, 2011; Ashofteh *et al.*, 2013; Singh, 2014; Barbosa-Povoa *et al.*, 2018), including several works on hydroeconomic models (Ward & Pulido-Velazquez, 2008; Harou *et al.*, 2010; Davidsen *et al.*, 2015; Martinsen *et al.*, 2019; Ward *et al.*, 2019), but we were only able to find one applied optimizing of plans for upgrading access to SDW (Schwetschenau *et al.*, 2019). Much more work is needed in this potentially fruitful type of investigation.

## 5. CONCLUSIONS

About one-quarter of the world's population still lacks effective access to SDW. Investigations that discover affordable and workable approaches to supply SDW internationally remain elusive. Quantitative analysis that informs the delivery of safe affordable drinking water has seen only limited attention in the peer-reviewed literature. Few works published to date have examined a range of economic, institutional, and governance factors influencing that access. As described in several points of this work, its original contribution is to investigate some of the more significant elements affecting that access to SDW internationally. Our work formulates, applies, and interprets data from 74 countries using annual data for the period 2012–2017. It contributes to our understanding of factors that are significant at influencing access to SDW. Results show that economic indicators play important roles. Higher levels of government effectiveness are also important. We were surprised that the avoidance of high levels of corruption and the protection of high levels of civil liberties showed weak effects. The results of our work carry important implications for guiding choices for communities who wish to supply access to safe affordable drinking water.

## COMPETING INTEREST

The authors declare no competing interests.

## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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