Assessment of Changes in Global Domestic Water Use and Economic Value

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Abstract

Water scarcity is a critical global issue impacting human life. Supply-side solutions alone do not meet the ever-increasing water demands. Economic assessment of water resources can reduce water scarcity risk by managing and prioritizing demand. This study aims to estimate domestic water withdrawal (DWW) and its economic value globally from 1980–2010. To represent the economic value, consumer surplus is calculated by building a demand function for each country, based on the water price at different levels of DWW per capita (DWWC). Global domestic water withdrawal increased by a factor of 2.1 in 2010 compared to 1980, with an average annual growth rate of 2.5%, while the population increased 1.5 times during the same period. In 2010, 93-645 million people, in particular, 93-500 million of the African population, did not have access to the basic water demand. The global average of DWWC's economic value is estimated as 2,015-4,076 USD in 2010 with a 5-6% increase from 1980 (1,909-3,884 USD). Also, it was found that, because of the low water prices, the economic values of domestic water are relatively low in some regions where water scarcity is one of the major societal problems (e.g., Middle Eastern and North African) compared to developed countries with a similar DWWC level. In such regions, toward sustainable water management, it is suggested to reconsider their policies adjusting water price and access to a fair water demand level. Therefore, the proposed framework would be beneficial for policymakers and international agencies to design sustainable water management systems.

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Key Points:

- An assessment framework was developed to quantify country-wise domestic water withdrawal and to assess its economic value.
- 12-57% of the global population could not meet basic water demand in 1980; however, it decreased to 1-9% in 2010.
- In many Asian and African countries, the economic value of domestic water is significantly below the global average.

Abstract

Water scarcity is a critical global issue impacting human life. Supply-side solutions alone do not meet the ever-increasing water demands. Economic assessment of water resources can reduce water scarcity risk by managing and prioritizing demand. This study aims to estimate domestic water withdrawal (DWW) and its economic value globally from 1980–2010. To represent the economic value, consumer surplus is calculated by building a demand function for each country, based on the water price at different levels of DWW per capita (DWWC). Global domestic water withdrawal increased by a factor of 2.1 in 2010 compared to 1980, with an average annual growth rate of 2.5%, while the population increased 1.5 times during the same period. In 2010, 93-645 million people, in particular, 93-500 million of the African population, did not have access to the basic water demand. The global average of DWWC's economic value is estimated as 2,015-4,076 USD in 2010 with a 5-6% increase from 1980 (1,909-3,884 USD). Also, it was found that, because of the low water prices, the economic values of domestic water are relatively low in some regions where water scarcity is one of the major societal problems (e.g., Middle Eastern and North African) compared to developed countries with a similar DWWC level. In such regions, toward sustainable water management, it is suggested to reconsider their policies adjusting water price and access to a fair water demand level. Therefore, the proposed framework would be beneficial for policymakers and international agencies to design sustainable water management systems.

1 Introduction

The World Economic Forum considers water scarcity a critical global risk, with a high impact on economies, environments, and human life (Jensen & Wu, 2018; World Economic Forum, 2019, 2020). Despite the urgency and importance, resolving water-related issues has not received enough attention by policymakers in public policy agenda (Madani, 2019). The "bankruptcy" of the water system is a reality many world regions face today, but decision makers' perception of the multitude of water system dynamics is poor; this prevents them from finding coherent and integrated solutions (Madani, 2019; Ristić & Madani, 2019). Many countries focus on supply-side measures to meet demand, such as extensive and costly infrastructure construction (with significant negative environmental impacts), whereas others believe supply-side solutions are not enough to meet the ever-increasing global demand (UN

Water, 2008). Approaches targeting demand management are necessary (Chen et al., 2005; Russell & Fielding, 2010; Wang et al., 2016).

Decision-makers need to make trade-offs among water use competitors (Loucks & van Beek, 2017). This becomes challenging as competition among water use sectors escalates (Zikos & Hagedorn, 2017). Since economics and engineering complement each other and share fundamental ideas, the economic management of water demand can aid in planning and decision-making (Lund et al., 2006). For instance, water pricing can control demand, recover costs, and increase economic efficiency, especially when water is scarce (Medellín-Azuara et al., 2012; Rinaudo et al., 2012; Rogers et al., 2002; F. A. Ward & Pulido-Velazquez, 2009). Additionally, the maximum economic benefit of water usage can be obtained through proper decision-making that allocates water based on the economic value produced by the users (Harou et al., 2009). Also, the impact of the economic aspect on water governance to secure access equality is indispensable in terms of basic water and sanitation services (Bayu et al., 2020). Therefore, along with assessing the quality and quantity of available water, it is crucial to consider the economic value related to water use, and potential water deficiency-related financial losses (Neverre & Dumas, 2015).

Although economic concepts have been applied widely in infrastructure management and system design (Lund et al., 2006), such economic valuations are mostly absent from water resource assessments (Neverre & Dumas, 2015). In this study, we focus on water demand in the domestic sector. Although domestic water has a lower share compared to other sectors (i.e., agriculture and industry) (FAO, 2016), it has a stronger connection to daily human life. Unlike other sectors (Oki et al., 2017), it cannot be compensated by a virtual water trade in case of water scarcity (Neverre & Dumas, 2015). In the absence of a global water market (Bierkens et al., 2019), it is difficult to estimate the economic value of domestic water and represent it as a monetary unit (Loucks & van Beek, 2017). To fill this gap, concerning the heterogeneity of economical situations among countries, we developed a general methodology to assess its economic value on a global scale. Moreover, for domestic water usage, economic value assessments are carried out by defining the demand function with a willingness to pay for different quantities of water (Young, 2005).

Several studies focus on global domestic water withdrawal (DWW) (Alcamo et al., 2003; Flörke et al., 2013; Hanasaki et al., 2013; Hejazi et al., 2013; Oki & Kanae, 2006; Shen et al., 2008; Shiklomanov, 2000; Wada et al., 2011b, 2011a, 2014). Some studies project DWW as a function of economic development (GDP) (Alcamo et al., 2003; Flörke et al., 2013; Oki & Kanae, 2006; Shen et al., 2008). WaterGAP was the first global hydrological model to project DWW with an empirical sub-model, using socio-economic data such as population and GDP per capita (Alcamo et al., 2003). The WaterGAP model incorporates structural and technological change concepts. Structural change means domestic water intensity (water use per capita) will increase rapidly with an increase in income (per capita GDP); thereafter, the growth rate will decrease gradually, and finally, reach saturation. Technological change refers to an increase in water use efficiency owing to technological development during the period under consideration. However, Hanasaki et al. (2013) stated that the relationship between income and water consumption is debatable; therefore, they proposed a different regression model, as a function of time, for 21 representative countries of each global region. Other studies consider alternative factors, such as water price in addition to socio-economic data (Hejazi et al., 2013), the urbanization rate (P. J. Ward et al., 2010), climate variables (i.e., temperature and precipitation; Hughes et al., 2010), and air temperature with urban and rural population accessibility rates (Wada et al., 2011a). To parameterize the characteristic of different countries to calculate DWW and associated economic value, in previous studies, we determined the advantage of the WaterGAP structure change concept (Alcamo et al., 2003) with additional consideration for the inflection point of water use per economic development.

Considering the importance of economic aspects of water resource management, this study aims to address the above gaps (i.e., economic value of DWW, heterogeneity of countries' characteristics) by estimating the economic value of domestic water use on a global scale. For this, first, DWW is calculated at the country-scale level, globally, for the period 1980–2010, using a logistic function similar to the WaterGAP's sigmoid function approach (Alcamo et al., 2003). Thereafter, the economic value of domestic water is calculated at the same spatial and temporal resolution. Referring to a previous regional study (Neverre & Dumas, 2015), we estimate the economic benefit of water demand by building the demand function using willingness to pay and domestic water use intensity.

2 Materials and Methods

2.1 Domestic Water Withdrawal Modeling

Inspired by the structural change approach of the WaterGAP model (Alcamo et al., 2003a), we propose an enhanced scheme to calculate DWW, globally. In structural change (Figure S1), water use intensity grows rapidly initially, then reaches a saturation point with economic growth, from low to high; represented by a logistic function. In some countries, historical DWW is far behind the saturation point, and in others, the available data are not sufficient. Therefore, a relationship in a coarser domain (e.g., regional division) is applied to those countries, thereby reducing the likelihood of unrealistic estimation (Alcamo et al., 2003a, 2003b; Flörke et al., 2013). Here, DWW for 52 and 142 countries are calculated based on country and region (194 countries in total), respectively. Regional divisions are set based on the UN composition of geographical regions definition (UNSD, 2011) along with modifications in some regions (Text S1). Equation 1 was applied to each country and region for the period 1980 to 2010 to determine DWW:

$$DWWC = \left({DWWC_{sat}} \Big/ {1 + e^{-\delta(GDPC - GDPC_0)}} \right) \qquad (1)$$

where $DWWC$ (m^3/year/cap) is domestic water withdrawal intensity in a given year, $DWWC_{sat}$(m^3/year/cap) is domestic water withdrawal intensity at the saturation point (the maximum domestic water withdrawal intensity), δ is the curve parameter, GDPC is GDP per capita in a given year, $GDPC_0$ is GPD per capita at the inflection point, respectively (Figure S1). In this method, we assumed that if GDPC is zero, there is no water withdrawal, and the minimum DWWC of each country cannot be less than the minimum regional DWWC to which it belongs. The DWWC phase will change at the inflection point ($dwwc_{inflection}$, Figure S1), and its growth rate starts decreasing until reaching the saturation point. For model performance evaluation, Willmott's index of agreement (Willmott et al., 2012) is calculated on the same spatial scale (Text S2).

2.2 Demand Function and Willingness to Pay

The value of water changes for different quantities and uses (Harou et al., 2009). Following Neverre and Dumas (2015), three-part demand functions are built in each country, in which each part represents the domestic water use for a different priority (Figure 1). The first part is the essential demand, e.g., preparing food, and hygiene; the second part is intermediate demand, e.g., taking a shower and laundry; and the last part is the least essential demand, e.g., a swimming pool or car washing (Neverre & Dumas, 2015). With the increasing quantity of demand, marginal willingness to pay (MWTP) will decrease (Harou et al., 2009). In building the demand function, the upper limit of each demand block (DW) and associated MWTP are determined. Minimum demand (DW_0) is set as 1 m^3/capita/year. For the first DW amount, two fixed values are applied. Based on previous studies, 7.3 m^3/capita/year (20 l/capita/day) (Fukuda et al., 2019; UN, 2017) and 18.25 m^3/capita/year (50 l/capita/day) (Gleick, 1996) are adopted as a basic human need (i.e., DW_1). For the upper limit of the second block (DW_2), DWWC at $dwwc_{inflection}$ is fixed. The inflection point ($dwwc_{inflection}$) is assumed to be an optimum access of water demand. At this point, the growth rate of water demand starts decreasing, as marginal utility of domestic water use diminishes. The DW_{max} is DWWC at the saturation point ($DWWC_{sat}$).

MWTP needs to be determined for each DW. MWTP for DW_0 ($MWTP_0$) is considered as the price of bottled water for each country (NationMaster, 2014). Here, we assume bottled water would be the most expensive accessible form to fulfill an immediate need. Since MWTP is directly affected by income, instead of assigning a fixed MWTP value for DW_1 and DW_2 for all countries with different income and development levels (Neverre & Dumas, 2015), this study uses the World Bank's criteria to group countries into 4 income categories (i.e., high, upper-middle, lower-middle, and low) based on gross national income (GNI) per capita (The World Bank Group, 2018). The income category for countries with gaps in GNI per capita data is considered using the first available year's data. The MWTPs for DW_1 and DW_2 ($MWTP_1$ and $MWTP_2$) are determined as the maximum surveyed water prices (IBNET, 2020) in each category, respectively (Text S3, Table S1). To derive the maximum price of upper-middle-income countries, an average of the maximum prices of lower-middle income and high-income countries is used. For MWTP of DW_{max} ($MWTP_{max}$), the available data on water price for each country is used (Text S3, Table 1). Table S2 summarizes DW_1 and $MWTP_1$, for different categories.

After calculating the domestic water intensity of each country from 1980 through 2010 from Eq.1 (DW_3, Figure 1), the associated MWTP ($MWTP_3$) can be obtained by the linear interpolation through demand function. By knowing all the required values of the demand function, consumer surplus as a representative of the economic value of DWW are calculated (Figure S2) by equation 2.

$$Consumer\ Surplus\ = \sum_{i=1}^{3} \frac{(MWTP_i - P_i) + (MWTP_{i-1} - P_i)}{2} \times (DW_i - DW_{i-1}) \qquad (2)$$

Where P_i is the water price for DW_i and $MWTP_i$. For DW_3, water price is equal to Pmax ($P_3 = P_{max}$, Figure 1)

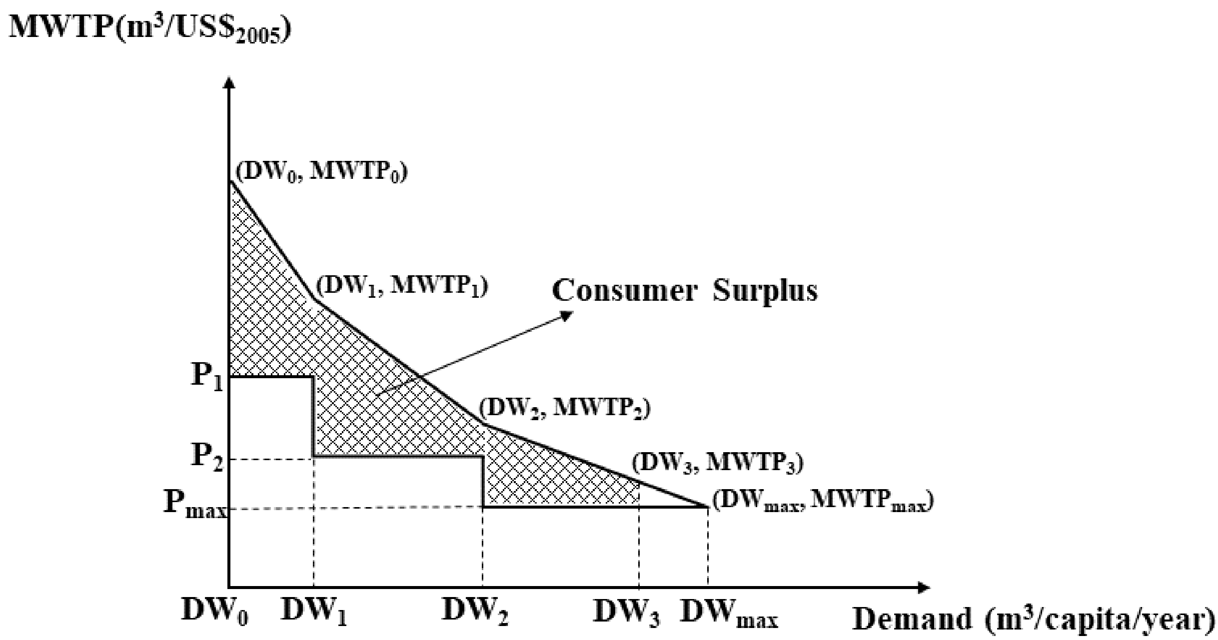

Figure 1. Three-part demand function. Area under demand function (consumer surplus) is considered as economic value of DWW. P_1, P_2 and P_{max} are water price of upper limit demand DW_1, DW_2, and DW_{max}, respectively. Area under three-part demand function varies between countries based on water pricing policy (Figure S2).

3 Data

3.1 Domestic Water Withdrawal

Annual DWW data, by country, were obtained from the AQUASTAT dataset (FAO, 2016). This dataset has broad international coverage and is a reliable water statistics source (Hejazi et al., 2013). For the United States and China, national data is used (USGS NWIS, 2020; Zhou et al., 2020). Based on the FAO definition, DWW in this data is the amount of water withdrawn by a public distribution network system that is connected to the municipal network. It can include renewable water e.g., surface water, groundwater, or fossil groundwater and treated wastewater. It covers water withdrawn for daily use e.g., drinking; cleaning; industry, which is connected to the public network; urban landscaping; and irrigation for urban areas (FAO, 2016; Hejazi et al., 2013).

3.2 GDP and Population

Country-based socio-economic data, GDP, and population, were taken from the Center of Global Environmental Research (CGER) (Murakami & Yamagata, 2019). The data were estimated by downscaling actual country population and GDP figures, from the International Monetary Fund (IMF) in grids (0.5 × 0.5°), for 1980-2010. They considered auxiliary variables such as city population, urban area, agriculture area, the total length of major roads, and distance to ocean and airport. For population levels in urban areas, they downscaled from countries to cities, and finally to grid levels; for non-urban areas, directly from countries to grids, since GDP was downscaled from countries to grid levels using downscaled populations (Murakami & Yamagata, 2019). Country scale population and GDP data were taken by upscaling grid value to the country.

3.3 Water Price

Water Price is obtained from The International Benchmarking Network for Water and Sanitation Utilities (IBNET) tariff data (IBNET, 2020). It is a city-wise and monthly dataset for global countries and primarily available after the year 2015. The most recent data from the capital or biggest city is collected. Text S3 provides more details. The price of bottled water is obtained for each country from a web database (NationMaster, 2014) (Text S3).

4 Results

4.1 Global Distributions of Domestic Water Withdrawal

After fitting the model—equation (1)—we found that the country-wise fitting result showed more agreement compared to regional fitting. In countries with more available data e.g., China, India, and the USA, the model performed better. For most countries in which DWWC reached the saturation level (i.e., $DWWC_{sat}$), such as European countries, although available data was sufficient, the fitting results were lower than countries with similar amounts of available data. This was because the model could not trace fluctuations after saturation (Figure S3). Figure S4 summarized the model's performance in Willmott's index and the comparison with the Water Futures and Solutions (WFaS) study (Wada et al., 2016).

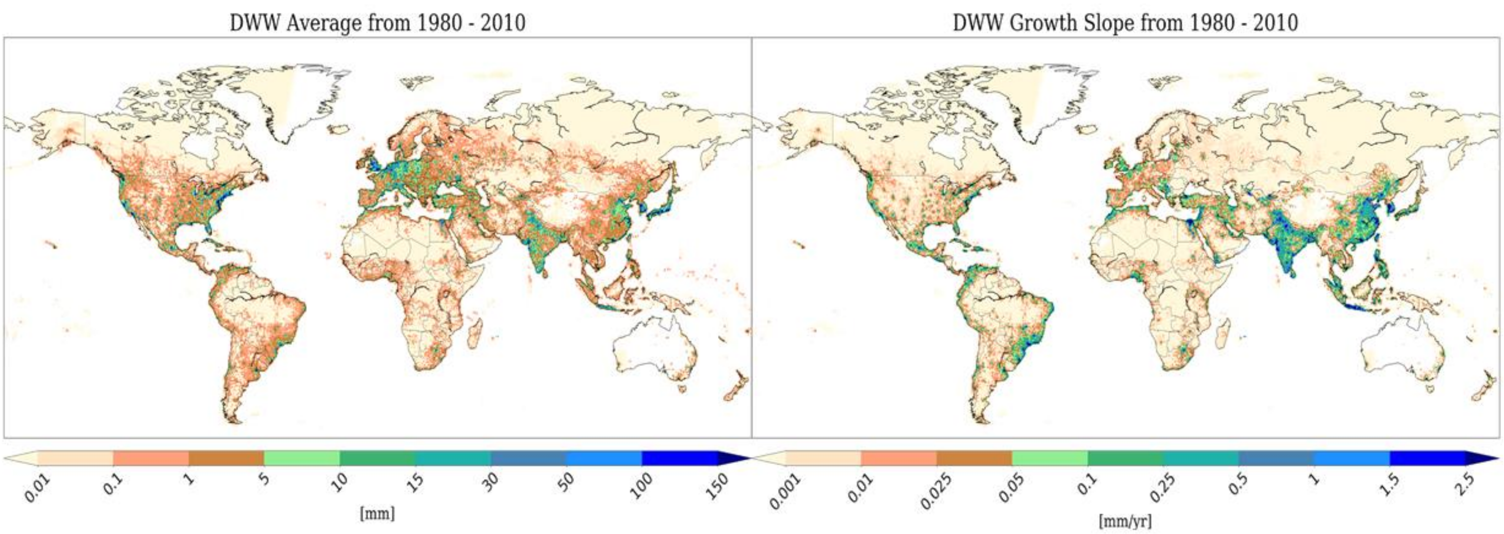

Figure 2. Global distribution of domestic water withdrawal (DWW) [mm] along with growth slope (slope of linear regression) on the grid scale (0.5 × 0.5°) from 1980 to 2010.

Figure 2 shows the global distribution of DWW (the country scale DWW is allocated to grid cells based on population distribution) and the growth rate from 1980 to 2010. In developed countries, such as the United States, Japan, and western European countries, and population-dense areas such as India and China, DWW was higher than other regions. In coastal areas and big cities, DWW tended to be high. The growth rate of DWW was relatively low in African countries, while in Egypt, along the Nile River, a substantial increase was estimated. The increase in DWW around the Nile River from

1980 to 2010 was significant compared to other global big rivers (population growth was high around the Nile River from 1980 to 2010). Despite water scarcity in the Middle East and North Africa (MENA), DWW was substantial, especially in urban areas. From 1990 to 2000, DWW change in Asia showed a significant increase (Figure S5), especially, due to population and economic wealth growth in China and India, where DWW continued to grow in 2010.

This study considered two different basic water demand levels. For 7.3 (18.25) m^3/cap/year, the global population that cannot access its basic water need decreased from 548 (2,564) million in 1980 to 93 (645) million in 2010. In 1980, the share constituted 12.7 (5.1) % from Africa and 63.2 (89.4) % from Asia, while in 2010 it changed significantly to 100 (77.5) % and 0 (20.9) % for Africa and Asia, respectively (Figure 3 and Table S3).

The global population increased by a factor of 1.5 and average annual growth rate of 1.4% over the period 1980-2010, whilst global DWW increased by a factor of 2.1 for the same period, exhibiting an average annual growth rate of 2.5%. Table 1 shows continental values for increased factor and growth rates for DWW, DWWC, and the population. In all continents except North America, the population growth rate was lower than the DWW growth rate (DWWC growth rate is negative in North America). The DWW growth rate for developed regions (e.g., Europe, North America, and Oceania), was lower than the regions of developing or under-developed countries. Additionally, the DWWC growth rates for such developed regions were negligible (< 1%). For countries within these continents, DWWC reached saturation demand (plateau in the sigmoid curve (Neverre & Dumas, 2015)). Asia and South America had the highest DWW and DWWC growth rates. In Africa, although DWW has increased by a factor of 2.8 from 1980-2010, DWWC was the lowest with the negligible growth rate (< 1%) (Tables 1 and S3).

The results of this study were comparable with estimates of preceding studies (Flörke et al., 2013; Shiklomanov, 2000; Wada et al., 2016) (Figure S5). DWW in 2010 was estimated as $454km^3$ by this study, and $390km^3$ and $472km^3$ for WaterGAP3 and Shiklomanov (Flörke et al., 2013; Shiklomanov, 2000), respectively.

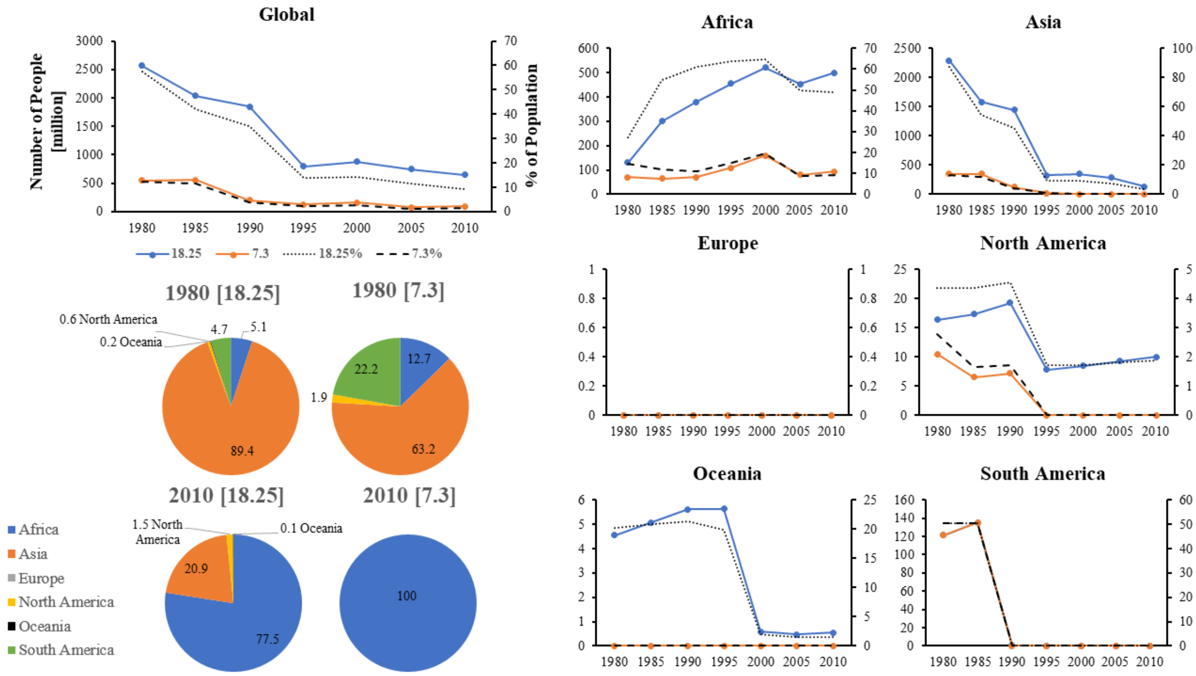

Figure 3. Number of People that cannot access to basic water requirement (18.25 and 7.3 m3/cap/year) on the continental scale in million. Pie Chat shows share of each continent in percentage for 1980 and 2010. For South America, values were almost the same for both basic demands (Table S3).

Table 1

Increased Factor and Average Annual Growth Rate of DWW, DWWC, and Population from 1980 to 2010 on The Continental Scale.

Continent	**DWW**		**DWWC**		**Population**	
	Increased factor	**Growth rate (%)**	**Increased factor**	**Growth rate (%)**	**Increased factor**	**Growth rate (%)**
Africa	2.8	3.5	1.3	0.9	2.1	2.6
Asia	3.6	4.4	2.3	2.8	1.6	1.5
Europe	1.1	0.4	1.1	0.2	1.0	0.2
North America	1.3	1.0	0.9	-0.2	1.4	1.2
Oceania	1.6	1.6	1.0	0.0	1.6	1.6
South America	4.2	5.0	2.6	3.3	1.6	1.6
Global	2.1	2.5	1.4	1.1	1.5	1.4

4.2 Demand Function and Economic Value of Domestic Water Use

Figure 4 shows how the MWTP changes for various demands for each continent and two basic demand values (i.e., 7.3 and 18.25 m^3/cap/year). For DW_0, Oceania had the highest MWTP (i.e., the highest bottled water price), and Asia had the lowest, whereas Africa had almost the same MWTP as Europe. For both basic water demands (i.e., DW_1), Africa had the lowest values of $MWTP_1$, and Europe the highest. Switching basic demand from 18.25 to 7.3 m^3/cap/year in the analysis increased $MWTP_1$ by 33% in all continents. In general, the MWTP for water in developed countries was higher than in developing countries. The demand curve over the second and third blocks was relatively flat compared to the first block, which shows water demand was less elastic for the first block than the second and third blocks since the MWTP of 1m^3 largely departed from basic demand. It was more obvious in Oceania where the slope was steepest, while Asia had the mildest slope for the first block. Also, the value change to 7.3 from 18.25 m^3/cap/year (i.e., basic demand in the first block) made the demand less elastic, and $MWTP_1$ became 2.7 times more sensitive to demand change in all continents. Oceania had the highest optimum and maximum water demand (i.e., DW_2 and DW_{max}). Asia, Europe, North America, and South America had similar DW_2 levels between 50 to 60 m^3/cap/year, while Africa and Oceania showed nearly half and twice of them, respectively. Europe's DW_2 and DW_{max} were only higher than Africa (almost at the same level as South America). The slope of the second block was significantly less steep compared to the first block, and it became steeper for the 7.3 m^3/cap/year basic demand. In contrast to the first block, Oceania had the weakest slope for the second block (Africa had the highest). In the third block, the demand function slope was identical for both basic demands. Similar to the second block, Africa and Oceania had the highest and lowest changes in MWTP to unit demand change, respectively. Since the demand function slope was necessarily flattest in the third block, people should be most sensitive to a price change in this block, which reflected the least essential character of water demand in this block.

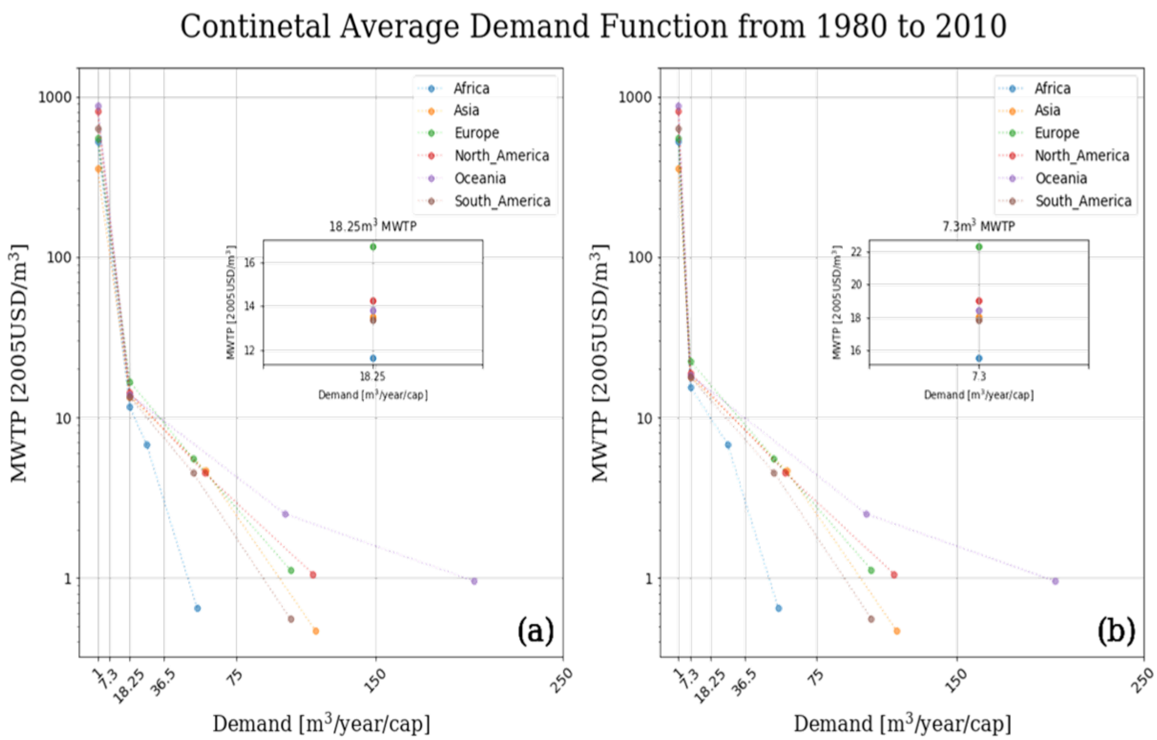

Figure 4. Continental average demand function from 1980 to 2010 for different basic demand (18.25 m3/cap/year basic demand (a), 7.3 m3/cap/year (b)). Y axis is the logarithmic scale.

In terms of the long-term (1980-2010) mean total consumer surplus (Figure 5a and b), the highest median value was captured in Oceania countries for both basic water demand, where more than half of countries in the region had more than 9,000 USD/cap and 4,000 USD/cap based on 18.25 and 7.3 m^3/cap/year of DW_1, respectively. The lowest median was captured in Asia with a value of almost 3,000 USD/cap and 1,500 USD/cap for each DW_1. Although consumer surplus in a few Asian countries (e.g., Japan, Singapore, and South Korea) was relatively high, the other Asian countries had shown lower values in comparison with countries in the other continents. In North America, the spread of economic values (i.e., consumer surplus) among countries was significantly larger than the other continents, which was indicated by the highest interquartile range (IQR, Q3 minus Q1). The distribution was skewed positively, and it may reflect the strong economic disparity within the continent. The lowest IQR was captured in South America, and Asia for 7.3 and 18.25 m^3/cap/year basic demands, respectively. It implied that inequality to access water services in countries (44 and 12 countries in Asia and

South America, respectively) within the continents was relatively low, but it is speculated that the lower economic values were due to the lower-income and water-rich climate.

Figures 5c and d show the 31 years average consumer surplus excluding the first block (basic human demand). Without the first block, consumer surplus reduction was significant, especially for 18.25 m^3/cap/year basic demand (MWTP for the first block was significantly higher than the other blocks). All continent median values were lower than the 400 USD/cap for both basic demands, and in Africa, the median value of economic values tended to zero for 18.25 m^3/cap/year basic demand, because the 2^{nd} and 3^{rd} blocks in the demand curve were not defined due to severe water access problems (i.e., water access lower than the basic human demand) in many countries. The biggest spread and median were captured in Oceania, where consumer surplus, demand, and tariff were significantly more dispersed, larger, and expensive, respectively, compared to other continents. In contrast to the first block, consumer surplus for the second and third blocks was relatively high in countries (mostly in developed nations) with a high level of DWWC and MWTP.

Figure 6 shows the average consumer surplus (USD/year/cap) from 1980 to 2010 by country level for different basic demands and demand blocks. The highest value of surplus was captured in Norway for both basic demands. It is obvious that using 7.3 m^3/cap/year as the basic demand led to a lower total consumer surplus than was the case with 18.25 m^3/cap/year basic demand. Setting a lower value for the basic demand had opposite impacts on the first and second block for consumer surplus. It reduced the first block's consumer surplus and increased it in the second block, while the third block's economic value remained unchanged (Figure 6). On a global average, 82.5, 15.1, and 2.4% and 94.7, 4.1, and 1.2% of total consumer surplus came from the first, second, and third blocks consumer surplus for 7.3 and 18.25 m^3/cap/year basic demands, respectively. Setting the less challenging goal for basic demand secures 192 of 194 countries in the world to fully satisfy the demand as similar to a previous study (Fukuda et al., 2019). As a result, except Eritrea and Somalia, all countries satisfied the basic water demand at least one year during the period. However, for 25 countries (mostly, African countries), we could not calculate the consumer surplus beyond the first block for the 18.25 m^3/cap/year basic demand since their demand did not reach the second block.

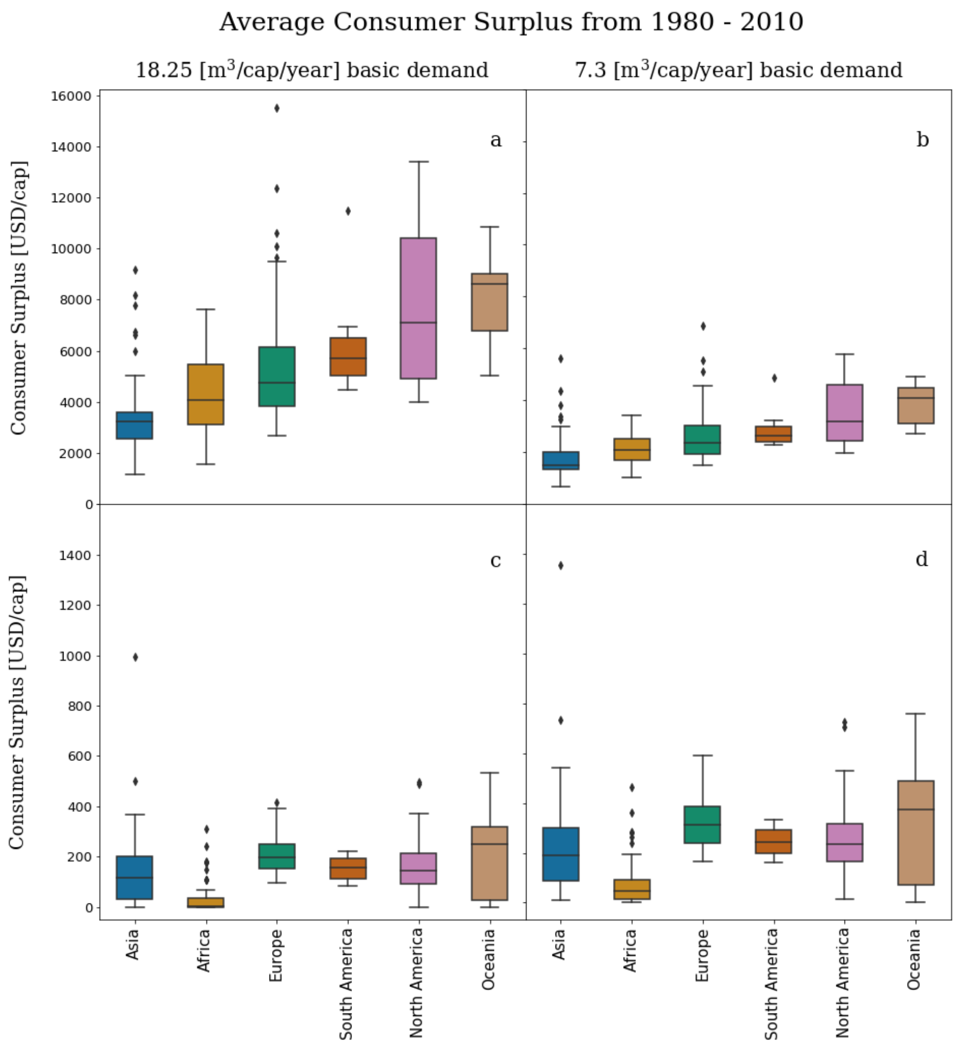

Figure 5. 31 years country average of consumer surplus [USD/cap] for each continent for different basic demands; all blocks (a and b) and only for 2nd and 3rd block (c and d).

Countries with a total consumer surplus higher than 6,000 USD/cap for 18.25 m^3/cap/year (2,750 USD/cap for 7.3 m^3/cap/year) can be divided into three groups. The first comprises countries that have high $MWTP_0$ mostly located in Africa where the DWWC value was much lower than developed countries, and even below the basic demand in some years. The second group includes countries like the United States, New Zealand, and Australia that had high values for both water pricing and DWWC compared to others. In these countries, a high consumer surplus value was due to high DWWC rather than prices of bottled water and tariff. The last group included mostly European countries, which had very high water prices, with high DWWC values. In such European countries, although DWWC was lower than countries with similar economic conditions such as United States and Australia, their surplus was relatively high, due to higher water prices. In the MENA region, with the same water use level (or higher) as European countries, the economic benefit of water use was smaller than these countries. The surplus was below 6,000 USD/cap (3,000 USD/cap for 7.3 m^3/cap/year), with some countries being below 3,500 USD/cap (1500 USD/cap for 7.3 m^3/cap/year). In arid regions, with the high pressure on water resources, consumer surplus was relatively low, while DWWC was at a high level. In general, water value was higher in developed countries compared to others. Also, in these countries, after reaching the saturation point, the surplus was constant or started decreasing gradually (Neverre & Dumas, 2015), but in developing countries surplus' were continuously increasing.

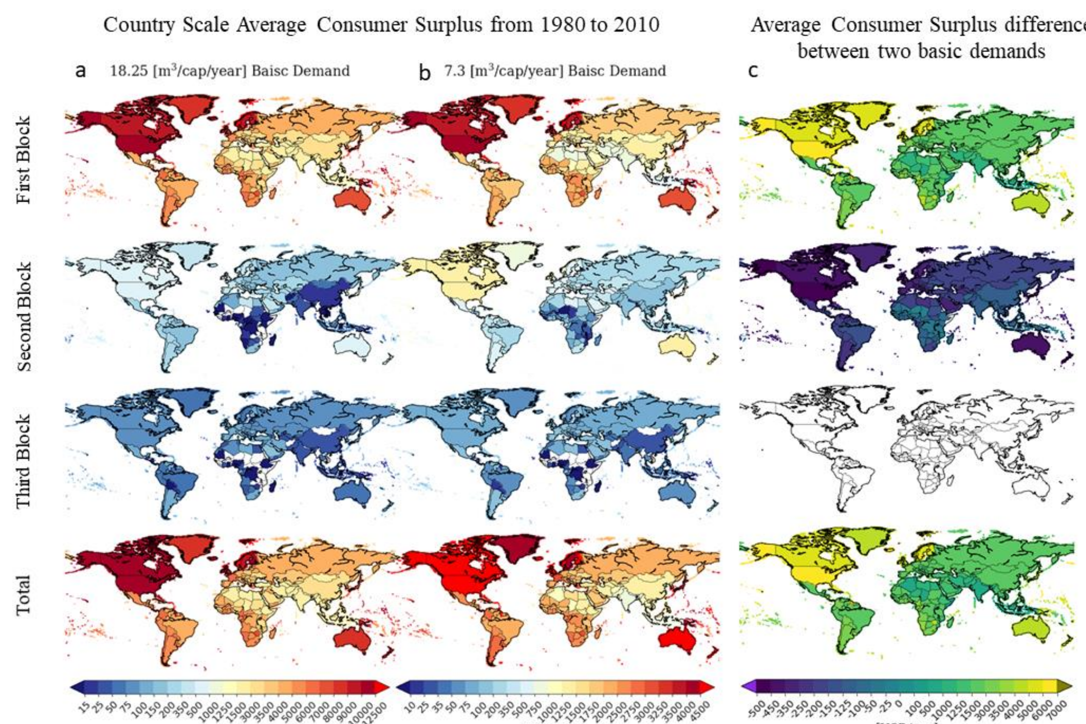

Figure 6. Average consumer surplus from 1980 to 2010 on the country scale for different basic demands (a and b) and its difference (c = a-b). Country consumer surplus is partitioned to each block of demand function, and total consumer surplus. Second and third block consumer surplus just appear for countries in which domestic water intensity is bigger than basic and intermediate demand. Consumer surplus is zero in white areas.

The long-term change of the global consumer surplus was not significant from 1980 to 2010. During the period, the global average surplus increased 4.9 and 5.6%, with an average annual growth rate of 0.16 and 0.18% for 18.25 and 7.3 m^3/cap/year basic demand, respectively (Table 2). The surplus growth rate was lower compared to the DWWC growth rate (1.1%). South America had the highest growth rate for both basic human demands. The lowest growth rate was shown in North America and Oceania for the demand of 7.3 m^3/cap/year and Africa and North America for the demand of 18.25 m^3/cap/year. In terms of surplus, North America and Asia indicated the highest and lowest value, respectively. Europe had relatively high water pricing, but domestic water intensity (i.e., DWWC; Table S3) was lower than Oceania and North America, hence, the difference in surplus was significant compared to North America and Oceania. The higher surplus value in Africa compared to Asia could result from the higher water price at 1m^3 (i.e., bottled water price). In Asia, the surplus value was below the global average consumer surplus, with more than 1,000 USD/cap difference (Table 2). In North America and Oceania, the surplus value was more than 3 times and 2 times greater than those of Asia and Africa, respectively.

Table 2

Continental Scale Consumer Surplus from 1980 to 2010[USD/cap]

Continent	**Consumer surplus [USD/cap]**						
	1980	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**
Africa	4109	4007	3738	3839	3837	3980	4074
	1938	1922	1911	1956	1957	1975	1995
Asia	2645	2705	2866	2934	2939	2966	2995
	1298	1322	1369	1400	1412	1436	1486
Europe	5025	5026	5023	5051	5077	5134	5177
	2473	2475	2471	2491	2511	2567	2604
North America	9532	9514	9515	9476	9416	9422	9434
	4663	4647	4671	4639	4611	4616	4629
Oceania	8397	8386	8376	8963	9017	9045	9067
	4407	4406	4404	4424	4444	4454	4469
South America	4336	4331	5381	5472	5493	5425	5535
	2312	2315	2513	2608	2634	2547	2688
Global	3884	3874	3970	4019	4011	4041	4076
	1909	1905	1930	1954	1958	1972	2015

Note. First line – consumer surplus for 18.25 [m^3/year/cap], second line consumer surplus for 7.3 [m^3/year/cap]

5 Summary and Concluding Remarks

This study calculated DWW at the country level, globally, for the period 1980 to 2010. Our results showed that DWW increased 2.3 times from 214 to 454 km^3yr^{-1}, from 1980 to 2010 with an annual growth rate of 2.5 %. Globally, DWW showed continuous growth during this period. In some developed nations such as the United States, from the early 1980s, the focus of water resource management shifted toward increasing efficiency and improving water pricing policies to control the endless increase of water demand (Arbues & Villanua, 2006; Gleick, 2000), but after 1990, due to the increase in economic wealth and the overall populations in Asia, South America and African nations (Flörke et al., 2013), the increase in DWW was significant. The highest growth rate was recorded in Asia and South America, and the lowest in North America. For the North American and Oceania regions, the increase in domestic water use efficiency (DWW growth rate was lower than or equal to population growth rate), can be attributed to a better water management. Africa had the lowest water intensity. This may be partly due to a lack of infrastructure and a well-equipped city-wide network distribution system and insufficient efforts (Gleick, 1996; Shiklomanov, 2000) that can restrict access to the correct water amount. Since European countries have a lower domestic water intensity level compared to countries with similar economic conditions, this can be attributed to other factors such as climate conditions (Huang et al., 2018) and cultural aspects in Europe.

Our results also showed that in 1980, almost 0.5-2.6 billion people could not access the basic amount of water, although this number decreased to almost 0.09-0.65 billion in 2010. Despite a growing number in Africa for the 7.3 m^3/cap/year basic demand, its share of the total population decreased from 15% in 1980 to 9% in 2010, in contrast, for 18.25 m^3/cap/year it increased from 27 to 49% during that time. Our model fitting results (Willmott's index) showed good model performance in regions with sufficient historical data. The agreement was low in countries in which DWWC reached the saturation point. Despite WaterGAP (Flörke et al., 2013) accounting for technological improvement, our study did not consider such an impact.

Finally, an economic assessment of domestic water was conducted globally. This study suggests the uniform approach for all countries, irrespective of economic situation, although this approach can be debated (Neverre & Dumas, 2015). The global average economic value of domestic water use only increased by a factor of 1-1.1, from 1909-3884 USD/cap/year in 1980 to

2015-4076 USD/cap/year in 2010, with a 0.2 % mean annual growth rate. North America had the highest economic value of domestic water use, while Asian countries had the lowest value. The average economic values in Asia at the continental scale were lower than the global average value. In terms of the demand function, Africa had a relatively high MWTP associated with 1 m^3 demand. Since most low-income countries are located in Africa, this can be explained by a lack of technology and infrastructure. Due to limited available DWWC data in the AQUASTAT dataset for Oceania (4 out of 13 countries), results of regional curve fitting seemed to have a bias toward a relatively high historical DWWC in Australia and New Zealand. This led Oceania to have a relatively large economic value of domestic water use. The demand curve showed inelasticity in the first block demand. This was expected because the first block of water demand is an essential demand; therefore, the quantity demanded does not change significantly with a change in MWTP. In some African countries that could not meet even the basic water requirement (7.3 and 18.25 m^3/year/cap), the economic value was higher than in developed countries. It can be argued that in these countries the lack of technology and infrastructure limits people from accessing enough water at a reasonable price, despite being rich in water resources (FAO, 2009); however, in general, the economic value of domestic water was far higher in developed countries compared to developing countries. We speculate that the absence of favorable country policies regarding water pricing can lead to the low economic value of DWW, especially in water-scarce areas such as the MENA region.

One limitation of this study was that we did not consider climate factors; for example, seasonal variations of temperature can affect water demand (Wada et al., 2011b). A second limitation of this study was that the cost of extracting water was not considered on the supply side. Due to groundwater depletion and the consequent water shortage, the water extraction cost will increase (Foster et al., 2015), which can affect its economic value as a result of increasing water tariffs. Therefore, considering supply-side cost parameters can increase the accuracy of future economic assessments of water use (Bierkens et al., 2019). A third limitation was related to water price data, because of lacking data, we applied a fixed water price to all the years. Additionally, quality-assured data for bottled water prices were not publicly available, we used an individual report-based web database. We conducted a consumer surplus analysis for each block separately (Figures 5b and 6), therefore, we assume the results were not significantly affected. Finally, since this study was conducted on the country scale, we could not capture variation within countries. DWW estimation on a country or regional scale, can lead to some unrealistic estimation and hidden real values; for example, in the United States, domestic water intensity in the Western area is higher than in the Eastern area (Rockaway et al., 2011), and rural and urban areas domestic water consumption is different due to the difference of supply efficiency (Hejazi et al., 2013). Estimation on a smaller scale is essential to obtain more detailed information on regional differences in water withdrawal (Bierkens et al., 2019; Huang et al., 2018). However, gaps in the methods of global domestic water use estimation remain.

By considering two values for basic demands (ambitious and less challenging) (Fukuda et al., 2019), this study successfully pictured populations by country who cannot satisfy their basic water need. This approach enabled us to investigate how defining basic water demand affects the economic value of domestic water use. This study proposed an enhanced approach including the inflection point to model country behavior toward water usage growth. By setting the inflection point as an optimum demand, we reflected on each countries' uniqueness in their demand function for DWW economic value calculation. Derived information from this analysis is indispensable to design accountable national and international water management policy. This framework can be applied at the regional level and in small-scale studies. Incorporating the details that have been neglected in the global-scale analysis and a finer assessment of the subsequent results is essential. With the calculation of other sectors' economic values, for instance, agriculture and industry, we can develop more efficient allocation policies to maximize the economic profit of water use (Bierkens et al., 2019) and reduce water shortage pressure. Also, it can be used for future projection of DWW, DWWC, and associated economic values.

Economic value has been considered for water-related assessment recently. However, the economic value of the domestic sector has received less attention on large-scale (global) assessments. Economic valuation is essential for integrated water resource management, and it can help reduce conflicts and water scarcity costs. For example, the high economic value of basic human demand can receive a high priority in allocation policy. Furthermore, a favorable pricing policy can increase economic value, and water use efficiency. This framework shows a global estimate of economic value for domestic water in heterogeneous economic conditions. It provides new information for further analysis for future adaptation policy under climate change.

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