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Residential Water Consumption Patterns: A Theoretical Review

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The global water crisis and acute increase in water demand have increased stress on water resources in urban areas, particularly in water-scarce regions like Egypt. Many current strategies of sustainable water demand management show low effectiveness due to a lack of understanding of how water is used in households, and a failure to consider the environmental and urban diversity that shapes water consumption patterns in Egypt. This understanding requires knowing how water is consumed for micro-components of water use (i.e., end-uses such as bathing, cooking, and toilet use). This research aims to develop a conceptual/theoretical framework for probable worldwide water consumption patterns and their shaping factors, to be used as an auxiliary tool in future data collection and analysis in Egypt, which is an essential step to contextualize water consumption patterns and develop more sustainable water demand management strategies. The study reviews and analyzes water end-use data from 39 major cities in developed and developing countries to identify trends and critical factors in household water consumption. It documents six different major trends in household water consumption patterns with main water activities: cooking, bathing, washing machines, faucets, and toilet use. It also identifies and categorizes the patterns-shaping factors into five main groups: socioeconomic characteristics, physical, spatial, climatic conditions, and political restrictions. Moreover, significant correlations emerge between pattern elements and shaping forces such as income and washing machine usage, the presence/absence of children/elders and use of basin, and dietary culture and cooking consumption. Given the research findings, household consumption patterns in Egyptian cities are expected to be high in kitchens, showers, and toilets, and average in laundry and faucets. The study underscores the importance of considering factors such as socio-economic characteristics, water policies, spatial influences, water supply efficiency, and consumer health in forthcoming investigations, as these are believed to substantially influence household water consumption in Egypt.

Keywords: urban water demand management, residential water consumption, patterns of consumption, household activities, end-uses.

Introduction

The global water crisis and the increasing demand have significantly strained water resources in urban areas worldwide. The United Nations estimates that 56% of the world's population live in urban areas, and the number is expected to rise to 68% by 2050, leading to further depletion of existing water resources (UN, 2020). The crisis is getting worse in many fast-growing deserts and semi-desert megacities, such as cities in the Middle East and North Africa (Abou-Rayan and Djebedjian, 2016; FAO, 2020), which have recorded extremely high levels of water stress exceeding 70% compared to the global average of 18.4%, due to rapid population growth, high rates of global urbanization, and climate change (IPCC, 2014; Thompson and Porras, 2001). Therefore, sustainable urban water management has become a challenge for those cities (Bradley, 2014).

Two of the 17 sustainable development goals released by the United Nations Resolution 70/1, titled "Transforming our world: the 2030 Agenda for Sustainable Development", underscore the concepts of sustainability and consumption in urbanization, namely goal 11: "Sustainable Cities and Communities" and goal 12: "Responsible Consumption and Production" (UN, 2015). Integrated Urban Water Management (IUWM) programs have been developed worldwide, combining improved supply reliability and demand-reduction strategies (Butler and Memon, 2006; Pullinger et al., 2013). However, many of the current water demand management (WDM) strategies, such as awareness-raising programs and water-saving technologies, exhibit low effectiveness in application due to an inadequate understanding of household water consumption dynamics (Chang et al., 2017; Hug and David, 2019; Adam et al., 2013). Cutts and Knox (2010) have indicated that the water use process in any urban community is one of a city's most critical production processes. This process is governed by social, economic, environmental, and institutional frameworks that must be known for applying consumption rationalization initiatives effectively.

Despite the current development in land use planning methodologies and water use efficiency studies in Egypt, there remains a lack of analytical capacity to address water demand and indicate a realistic urban development scenario with sustainable water consumption (Roshan and Kumar, 2020). This may be due to the Egyptian Code for Designing Drinking Water and Sanitation Networks (HBRC, 2010) used to estimate per capita consumption (PCC) and water demand. This code sets constant values for PCC based on average annual consumption and relative to the urban classifications used (i.e., new cities, existing cities, capitals, major cities, etc.) without considering the different environmental, urban, and social patterns that characterize Egypt and affect water use behavior and consumption rates. Technical criteria for planning and implementing utility networks are formulated according to these values (GOPP, 2011; Roshan and Kumar, 2020). Moreover, governments and policymakers focus on the general targets for reducing water consumption while understanding the reality of use, consumption patterns, and market mechanisms essential in achieving those targets (Stoker, 2016; Khattan and Alrawy, 2017; Adams et al., 2013).

Achieving a comprehensive understanding of water consumption requires knowing the total residential water consumption and the users' behavior regarding consumption of the micro-components of water use or "end-uses," as mentioned in many literatures (i.e., water consumed by activities such as kitchen, toilet use, bathing, gardening, and others) (Roshan and Kumar, 2020; Adams et al., 2013; Yao, 2013; Willis et al., 2011). In this context, the residential family seems to be the primary unit for analyzing consumer and water consumption relationships (Lee et al., 2012; Yao, 2013; Bradley, 2014).

Water consumption patterns (WCP) studies provide a valuable tool for developing more effective and sustainable WDM strategies at different spatial scales, using measurements of household water end-uses. The WCP studies provide planners and policymakers with data and information for different water use activities and their dimensions (such as flow rates, frequency, and duration of use). It also reveals factors that govern water consumption, such as family size, income level, education, household area, device technology, water prices, and climate conditions (Yao, 2013; Matos et al., 2013; Fan et al., 2017; Rathnayaka et al., 2017; Oduro et al., 2018; Bich-Ngoc and Teller, 2018; Khattan and Alrawy, 2017; Roshan and Kumar, 2020; Chang et al., 2013). Such information leads to more accurate and realistic estimates of residential water demand, improving the efficiency of the current WDM strategies by knowing where and how to use them (Sadr et al., 2017; Gato-Trinidad, 2011). In Singapore, for example, water consumption for bathing is high (73 L/p/d, representing 45% of total domestic consumption); and providing financial incentives for installing low-flow shower heads is an effective policy to reduce consumption. In contrast, such a policy is useless in Hamburg, Germany, where the water consumption for showering is only 30 L/p/d (Rathnayaka et al., 2017).

Recently, WCP studies have also included spatial household water consumption models for different urban typologies and socioeconomic groups within a city. These models can shape new low-water urban planning approaches with site-specific consumption reduction strategies (Otaki et al., 2008; Fan et al., 2017; Jiang, 2013; Makki et al., 2014; Turner et al., 2004). According to De Oreó and Mayar (1999), understanding WCP can reduce water demand by 30–50% without affecting people's lifestyle or level of service. This effectively reduces wastewater flows and eases water pressure on infrastructure networks, especially during peak times, lowering the water supply expansion costs, operations, and maintenance works (Samuel, 1986; Puvanisha et al., 2020; Matos, 2013). Additionally, it mitigates the burden on ecosystems and the water footprint in urban areas (Roshan and Kumar, 2020).

However, there is a lack of current literature related to residential WCP, not only within Egypt and developing cities but also theoretically, in terms of comprehensiveness. Previous studies worldwide focus on a specific city or country or explain one or several groups of influencing factors without providing a comprehensive view of all possible patterns and factors to be used as a nucleus for future studies.

In this context, the research aims to develop a conceptual/theoretical framework for different possible residential water consumption patterns worldwide and their shaping forces by conducting a comparative analysis of all available end-use data to identify trends, variations, and correlations in how people with different backgrounds use water. This theoretical framework will facilitate data collection in future studies to identify residential WCP in Egyptian cities and worldwide. These subsequent studies can validate, differ, or expand the theoretical background. To our knowledge, this is the first study to analyze and contextualize global residential water consumption patterns.

Residential water use can be split into indoor and outdoor water usage. Indoor usage includes cooking, dishwashing, laundry, bathing, and toilet flushing, while outdoor activities include irrigation, swimming pool filling, and car washing. This study focuses on identifying and analyzing residential indoor WCPs, as there is less uncertainty about factors influencing water consumption than the more complex and variable factors affecting outdoor usage, making it challenging to identify their patterns (Roshan and Kumar, 2020).

The study analyzes indoor water end-use data for 39 major cities across 25 developed and developing countries, with different climatic conditions and socioeconomic characteristics, providing three significant contributions:

1 Identifying the current trends in residential WCPs worldwide and discussing similarities and differences in residential water use for urban communities.

2 Contextualizing the factors shaping WCPs, identifying the key factors influencing water consumption, and discussing significant correlations between various factors and water end-use by activity;

3 Based on the results of the first two aspects, the research highlights the expected residential WCPs in Egyptian cities and the factors that must be considered in future studies, given the specificity of Egyptian society.

Methods

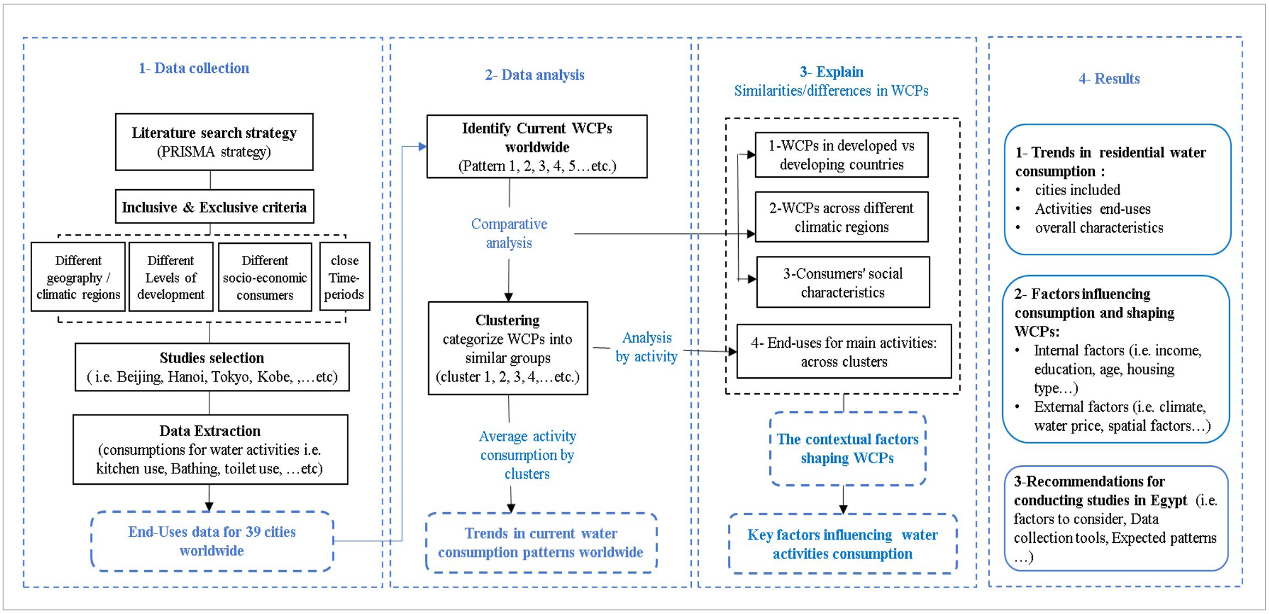
The study methodology is divided into four consecutive steps: 1) data collection, 2) data analysis, 3) an explanation of the differences/similarities in household water consumption, and 4) results, including the study results and recommendations for conducting future studies in Egypt. *Fig. 1* shows the four steps described more accurately in the following sub-sections.

Data collection

The research followed PRISMA guidelines for literature review and data collection on water end-uses for different cities worldwide according to the following stages (PRISMA, 2019):

1 Literature search strategy. Relevant literature was searched using keywords such as "domestic or residential water use", "water consumption patterns", "end-uses", "water activities", and "micro components of water use" at various publication platforms like Scopus, Web of Science, ResearchGate, and Google Scholar. Additionally, relevant reports and country-specific data were obtained from websites and UN bodies like UNDP, WHO, and UNEP.

Fig. 1. *Steps in the methodology*



2 Inclusive and exclusive criteria. Various criteria were established to include or exclude the literature from the research for review. These criteria include studies conducted at the water use activity level, providing accurate data about water end-uses, representing different levels of economic progress and quality of life, and ensuring consumers' climatic/geographical differences and socioeconomic diversity.

3 Case study selection. Studies that provided accurate data on water end-use and were conducted in similar periods were selected for inclusion in the research. Accordingly, residential water consumption data from 39 studies conducted in 25 different countries were utilized, as shown in *Table 1*. These studies were

Table 1. *List of cities included in the research*

Country	City	Survey year	Country	City	Survey year
China	Beijing	2013	Sweden	Stockholm	2011
	Hebei	2013	German	Hamburg	2012
	Harbin	2017	France	"Total"	2011
India	Haryana	2011	Australia	Perth	2019
	Jaipur	2017		Sydney, South Wales	2012
Sri Lanka	Trinco Mali	2010		Auckland, New Zealand	2016
South Korea	«Total"	2012		Brisbane, Queensland	2010
Singapore	«Total"	2016		Gold cost, Queensland	2018
Vietnam	Hanoi	2013		Melbourne, Victoria	2011
Thailand	Chiang Mai	2014	Uganda, Tanzania and Kenya (total)		2011
Taiwan	Taipei	2012	Brazil	Florianopolis	2013
Japan	Cobi	2010	Peru	Lima	2019
	Tokyo	2007	USA	San Francisco, California	2018
UAE	Dubai	2013		Boulder, Colorado	2017
England	Cambridge	2014		Denver, Colorado	2017
Switzerland	Zurich	2010		Phoenix, Arizona	2016
Netherlands	Amsterdam	2017		Tampa, Florida	2017
Austria	Vienna	2012		Atlanta, Georgia	2017
Portugal	"Total"	2011	Canada	Winnipeg, Manitoba	2011
Span	Barcelona	2016			

distributed as follows: 9 studies of European cities in the countries of England, Portugal, Spain, Switzerland, the Netherlands, Austria, Sweden, France, and Germany; 14 major cities in Asian countries: Thailand, Taiwan, South Korea, China, Japan, Taiwan, Vietnam, India, Singapore, Sri Lanka, and the United Arab Emirates; 6 major cities from Australia, namely: Perth, New Zealand, Queensland, Victoria, and South Wales; 7 major cities in Canada and the United States of America (in the states of San Francisco, Colorado, Arizona, Florida, and Georgia); and two studies in the countries of Peru and Brazil in South America, and an aggregated study of water consumption for major cities in Central East Africa countries, namely Uganda, Kenya, and Nairobi.

4 Data extraction. End-use data for major water activities, namely kitchen uses, bathing, toilets, faucets, and laundry, were extracted and recorded for analysis.

Data analysis

Based on the research question, quantitative and qualitative analyses of case study data are conducted to discover current trends in WCPs and the key factors shaping them. As a first step, we conducted a statistical analysis of end-use values from case studies to achieve a general understanding of the current WCP globally. Subsequently, a comparative analysis of end-use values was conducted to identify prevailing patterns and similarities/differences in residential water consumption between cities. Accordingly, we conducted a cluster analysis by categorizing and clustering the case studies with similar patterns according to their end-use values into similar groups, each representing a global trend/main pattern of residential water consumption.

The study also uses qualitative methods such as content analysis of case studies to interpret the resulting trends, the similarities/differences in water consumption and discover the factors shaping these patterns, such as analyzing WCPs across different groups of developed and developing countries and groups of countries/cities in different climatic zones. In addition to analyzing end-uses by main water activities, namely, bathing, toilet flushing, indoor taps, laundry, and kitchen uses.

Explain the similarities/differences in residential water use

This step aims to clarify and discuss the reasons/factors that shape WCP and influent water consumption by conducting. Moreover, it accurately identifies the essential and contributing factors that influence water consumption by each activity and disccloses which factor(s) are the key to household water consumption.

Results

This step shows three parts: trends in residential water consumption, with cities included, average activities end-uses, and overall characteristics of the pattern; factors influencing consumption and shaping WCPs internal factors (i.e. income, education, age, housing type, etc.) and external factors (i.e., climate, water price, spatial factors, etc.); and recommendations for conducting studies in Egypt (i.e., factors to consider, data collection tools, expected patterns, etc.).

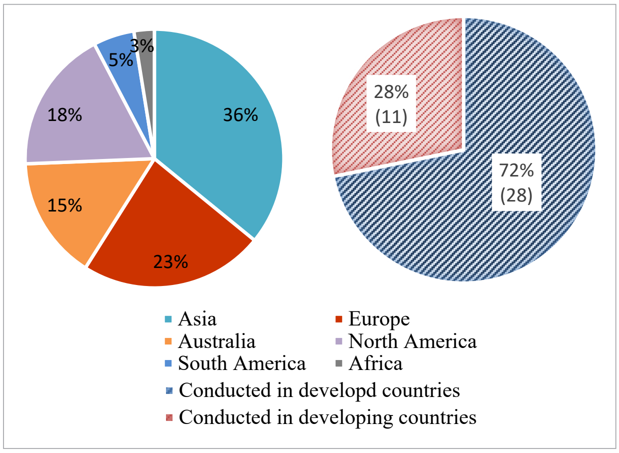
Results and Discussion

Distribution of end-use studies

Residential end-use studies conducted worldwide were not uniform spatially or temporally. End-use studies involved in the research were primarily carried out either at a specific city or district level (Chang et al., 2017; Sadr et al., 2017; Samuel, 1986; Khattan and Alrawy, 2017; Yao, 2013; Oduro et al., 2018; Otaki at al., 2008; Otaki at al., 2013; Jiang, 2013; Bradley, 2014; Chowdhury et al., 2015; Sivakumaran and Aramaki, 2010; De Oreó, 1999; Makki et al., 2014; Shan et al., 2015; Park and Jeong, 2012), or at the country level, such as in France, Portugal, Singapore, South Korea, and the countries of east Africa (Otaki et al., 2014; Park and Jeong, 2012; Grafton et al., 2011; Willis et al., 2011; Thompson and Porras, 2001).

Fig. 2 illustrates the distribution of the WCP studies included in this research. Chart (a) shows a continental-wise distribution of studies, while chart (b) shows studies conducted in developing versus developed countries. Chart (a) reveals that many WCP studies have dealt with Asian countries, especially developed ones such as Japan, Singapore (Otaki, 2017), and Korea (Thompson and Porras, 2001). Others have dealt with European countries such as the United Kingdom (Neunteufel et al., 2014; Stoker, 2016) and Spain (Kumar et al., 2020), in addition to other studies of Australian cities such as Perth (Turner et al., 2004), Victoria (Al-Sumati et al., 2020), and South Wales (Morote et al., 2016). Some studies have dealt, to a lesser extent,

Fig. 2. *Pie chart depicting the end-use studies conducted a) across continental-wise distribution, and b) in developing vs developed countries*



with water consumption in the USA (Pullinger et al., 2013; Otaki et al., 2014) and Canada (Grafton et al., 2011). Studies were limited to the Middle East, Africa, and South American countries such as Brazil and Peru (Shan et al., 2015). There is only one study of WCP in the Middle East conducted in the United Arab Emirates (Roshan and Kumar, 2020), in addition to another study of the Central East African countries (Kenya, Tanzania, and Uganda) (Samuel, 1986), even though African countries consume more than 15% of the world's clean water resources (Thompson and Porras, 2001).

On the other hand, most of the water end-use studies have mainly focused on developed countries. As is evident from *Fig. 2* (chart b), approximately 72% of the water end-use studies, representing 16 countries (28 cities), reported in this paper have been conducted in the developed nations, while 28% of the studies, representing nine countries (11 cities), were conducted in developing countries such as India, China, Vietnam, Sri Lanka, and Peru. Moreover, many studies conducted in some developed countries were concentrated in one region, despite many countries' climatic/geographical diversity, such as the UK and the USA.

The studies included in this research also represent different climatic conditions, which helps to understand better the relationship between residential water consumption and climatic conditions (Matos et al., 2013; Hug and David, 2019; Knox and Cutts, 2010). It included studies conducted in hot climate regions such as Jaipur, India; Arizona, USA; Peru; and the UAE; others were conducted in the temperate areas in Australia, central and southeastern USA, Thailand, Singapore, and Portugal; in addition to studies conducted in cold climate regions in Canada, Colorado in the USA, northern China, and northern and central Europe. Despite the limited data for WCP studies, particularly in developing countries, which prevents achieving a complete representation of WCP worldwide, the spatial, climatic, and socioeconomic diversity of the available data presents one of the leading research challenges for developing a comprehensive view of current WCPs and their underlying factors.

Residential water consumption patterns around the world

Comparative analyses of water end-uses across different cities

We have reviewed 39 case studies conducted in both developed and developing countries (n = 25) from Europe, Asia, Australia, and North and South America, in addition to one study from Africa, representing different urban typologies and socioeconomic groups. We focused on studies that provided accurate data on water end-use and were conducted in similar periods. Only indoor end-uses (shower/bathtub, toilet flushing, kitchen uses, indoor taps, laundry, and any other leakages) were considered for this study. Water consumption within households is measured in liters "per capita", which is liters / per capita / day or L/C/P, which was used as a unit of analysis for the data contained in this research. A comparative analysis of end-use values in these studies was conducted and the results obtained are presented in *Table 2* (listed in Appendix 1). Dubai (United Arab Emirates), Taipei (Taiwan), Winnipeg (Canada), and Arizona (United Arab Emirates) had the highest water consumption for internal water uses, reaching 280, 270, 250, and 260 L/c/d respectively, while European, Australian cities had the least consuming water, with an average consumption of 120 L/c/d. The main generalized findings of the comparative analysis can be summarized as follows:

1 The comparative analysis of case studies data reveals varing patterns of water consumption across cities. It indicates that several factors and parameters govern water usage, including water resources, education, socio-economic development, environmental beliefs, family size, water prices, and climatic conditions. These factors are detailed in section 3-3, namely the factors affecting residential water consumption, which discusses how they influence household water use.

Table 3. *Description of current trends in residential water consumption patterns worldwide*

Trends	Cities/Countries	Average end-use for main water use activities (liter/ person/ day)					
		Kitchen uses	Shower/ bathtub	Toilets	Faucets	Laundry	Others*
Pattern A	Beijing, China Trinco alee, Sri Lanka Amsterdam, Netherlands Perth, Australia Sydney, South Wales, Aus. Auckland, New Zealand Brisbane, Queensland, Aus. Gold cost, Queensland, Aus. Melbourne, Victoria, Aus. Uganda, Tanzania and Kenya**	< 10	60–40	20–35	20–30	15–30	5–20
Pattern B	Hebei, China Harbin, China Hanoi, Vietnam Haryana, India South Korea (total) Cambridge, England, UK Hamburg, German Lima, Peru	10–20	25–40	30–40	10–20	15–30	< 10
Pattern C	San Francisco, California, USA Boulder, Colorado, USA Denver, Colorado, USA Phoenix, Arizona, USA Tampa, Florida, USA Atlanta, Georgia, USA	< 10	40–60	60–80	40–50	50–70	< 10
Pattern D	Chiang Mai, Thailand Tokyo, Japan*** Kobi, Japan*** Winnipeg, Canada **** Stockholm, Sweden France (total) Singapore (total) Jaipur, India Florianopolis, Brazil	20–35 (in-creases to 50–60 in Japan)	60–80 (increases to 90 in Canada)	30-50 (increases to 76 in Canada)	10–30	20–50	< 10
Pattern E	Dubai, UAE Taipei, Taiwan	35–65	100–130	50	40–50	10–20	< 10
Pattern F	Vienna, Austria Zurich, Switzerland Portugal (total) Barcelona, Span	< 10	30–50	25-35	25–45	10–20	10–20

* Other uses include sub-consumptions such as cleaning floors, washing cars, water leaks and others.

** Faucets and toilets end-uses in the cities of Central East Africa decrease to 10–15 L/p/d.

*** Kitchen water end-uses in Japan increase to 50–60 L/p/d.

**** Toilets and shower water end-uses in Winnipeg, Canada increase to 76 and 90 L/p/d, respectively.

2 There is a remarkable variation of water end-uses among Asian cities (such as Thailand, China, India, the United Arab Emirates, Singapore, etc.) due to the different climatic, economic, and social conditions between Asian countries. On the other hand, water end-use values for all activities in the sample representing African countries have been low due to the current shortage in water supply.

3 Moreover, there is a decrease in the amount of water used for kitchen uses, and laundry in European cities compared to Asian cities, due to the low family size, with stable basic needs such as washing clothes. In addition, there is a decrease in the amount of water used for bathing in most developed countries due to the use of more efficient devices in water consumption, increased awareness, and critical government restrictions.

4 Statistical analyses also indicate an increase in water consumption of basin taps in Canada and the United States of America, compared to European countries, despite the high economic and technological levels and low temperatures, due to the low-density horizontal urbanization compared to the higher density in Europe.

5 There is an increase in water consumption for showers and toilets in hot-climate countries such as Peru, (Brazil) India, Vietnam, the United Arab Emirates, and Queensland (Australia).

The comparative analysis conducted helped identify the prevailing trends in water consumption globally and explain similarities/differences in using water between cities. We categorized and clustered the cities with similar patterns (end-use values) into similar groups (as shown in *Fig. 4*), shaping trends in residential water consumption patterns. *Fig. 3* (listed in Appendix B) also shows a distribution of water consumption patterns, clustered by similar patterns. Average end-use values for each cluster refer to the values of a trend (as shown in *Fig. 5*). Accordingly, six main trends of water consumption patterns were identified. *Table 3* provides a characterization of these trends, the cities covered by each, and the average water end-use values per activity, which are described below:

Pattern A. Out of all the cities included in the sample, it includes ten major cities, specifically from Australia: Perth, Sydney, Auckland, Brisbane, Gold Coast, and Melbourne; additionally, it includes cities from Asia, Europe, and Africa: Beijing, China; Amsterdam, Netherlands; Trinco Alee, Sri Lanka; and a combined pattern of Uganda, Kenya, and Tanzania in Africa. In addition to being the least water-intensive, pattern A is one of the most popular homes WCPs and the least water consuming. Bathing is the most water consuming activity in this pattern. The most water intensive activity in this pattern is bathing, which uses 40–60 L/p/d. Water consumption for faucets, toilets, and laundry drops to 20–35 L/p/d. Cooking is an activity that uses less than 10 L/p/d and uses the least amount of water. Central East African cities have the lowest water consumption, particularly in toilets and faucets, due to the lack of water supplies and reliance on outside water sources for essential requirements. Despite spatial, climatic, and socioeconomic differences, the significant impacts of water policies and water supplies in these cities were the critical factors for the similarity of water end-uses between cities (Thompson and Porras, 2001).

Pattern B. There are eight large cities in this pattern. Asian cities in developing countries dominate this pattern, including six major cities: Hebei and Harbin, China; Hanoi, Vietnam; Haryana, India; South Korea; Cambridge, England; and Lima, Peru. It uses the most minor water, with showers averaging 25–40 L/p/d and 10–20 L/p/d for indoor taps. An estimated 10–20 L/p/d is used in kitchens, 30–40 L/p/d in toilets, and 15–30 L/p/d in laundry. Notably, Cambridge has minor water consumption in kitchen use due to European society's low water-consuming food culture (Hug and David, 2019; Pullinger et al., 2013).

Pattern C. This pattern includes six significant American cities: San Francisco, California; Denver, Colorado; Boulder, Colorado; Phoenix, Arizona; Tampa, Florida; and Atlanta, Georgia. Pattern C has the highest water consumption, especially in toilets and laundry. The most water intensive activity in pattern C is using toilets, which use between 60 and 80 L/p/d on average. Other activities also saw a less dramatic increase in water consumption, with washing clothes using 50–70 L/p/d, indoor faucets using 40–50 L/p/d, showering using 40–60 L/p/d, and kitchens using 10 L/p/d being the minor water intensive activities. While American cities tend to use water similarly, Phoenix records slight increases in water consumption for showering, faucets, and laundry compared to other states. This could be primarily due to the high temperatures in southern Arizona, where the city is located (Otaki, 2014).

Fig. 4. *Clusters of similar water consumption patterns shape the major trends*

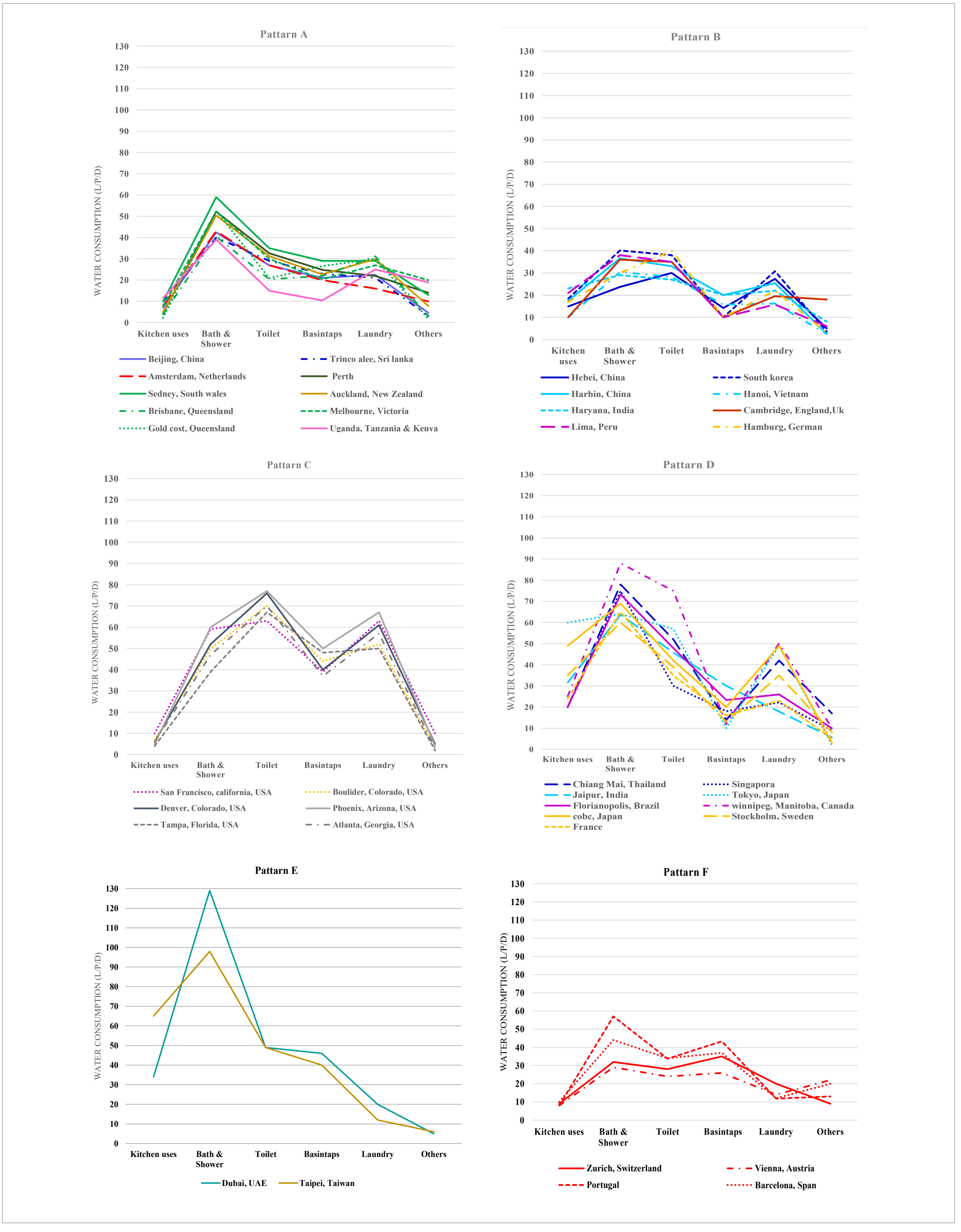
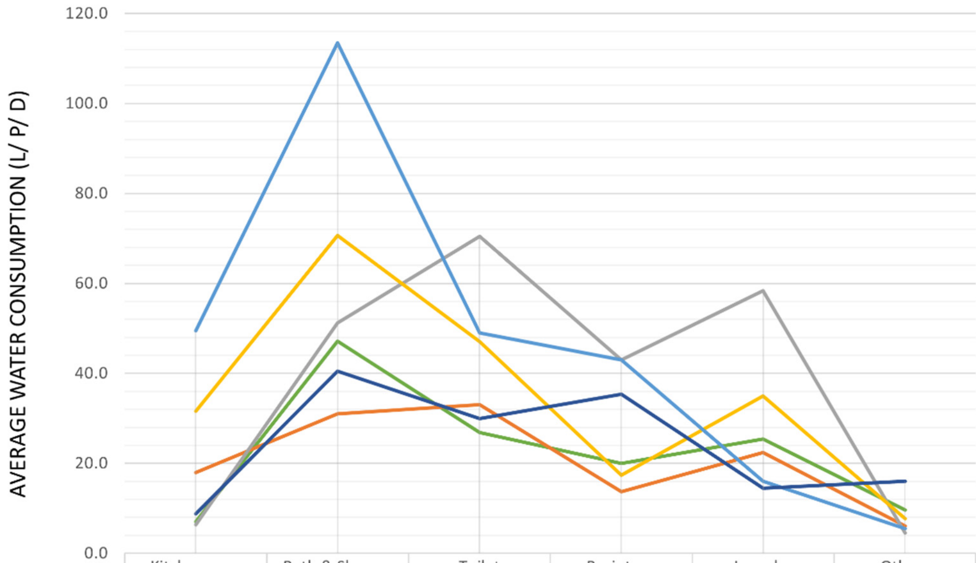


Fig. 5. *Worldwide trends in residential water consumption by activity*



	Kitchen uses	Bath & Shower	Toilet	Basintaps	Laundry	Others
Pattern A	7.0	47.1	26.8	20.0	25.4	9.6
Pattern B	18.0	31.0	33.0	13.7	22.4	6.1
Pattern c	6.3	51.2	70.5	43.0	58.3	4.5
Pattern D	31.6	70.7	47.1	17.4	34.9	7.7
Pattern E	49.5	113.5	49.0	43.0	16.0	5.5
Pattern F	8.8	40.5	29.9	35.3	14.5	16

Pattern D. The nine essential cities in this mixed pattern include Tokyo and Cobi, Jiban; Chiang Mai, Thailand; Stockholm, Sweden; Winnipeg, Canada; and other cities in Europe, Asia, and South America. Along with Singapore and France, there is Hamburg, Germany; Jaipur, India; and Florianopolis, Brazil. Indoor taps use the least amount of water in this category, ranging from 10 to 30 L/p/d, while bathing uses the most, ranging from 60 to 80 L/p/d. The typical amount of water used for other uses is 20–50 L/p/d for laundry, 20–50 L/p/d for toilet flushing, and 20–35 L/p/d for kitchen use. Despite the similarity in the general patterns among cities, there is a variation for some activities, such as bathing and toilet flushing in Winnipeg, that rises to 90 L/p/d and 76 L/p/d, despite the high economic progress level and low temperatures due to the lack of consumption reduction policies, such as water price and taxes. Water consumption for kitchen uses in Kobe and Tokyo has also increased to 50–60 L/p/d due to the dietary culture that relies more on home meals (Otaki et al., 2008; 2014).

Pattern E. This pattern represents only two cities: Al-Ain, UAE, and Taipei, Taiwan. Bathing/showering is the most water consuming activity in this category, with per capita consumption of 129 L/p/d in Dubai, which is the highest consumption in the world as well (Bich-Ngoc and Teller, 2018) and 98 L/p/d in Taipei. This is due to the spread of tourist housing patterns in both cities, affecting the luxury of use, especially bathing (Chowdhury et al., 2015). Water consumption also increases in kitchens, reaching 35 L/p/d in Dubai and 65 L/p/d in Taipei, while it decreases in laundry to 10–20 L/p/d for both cities. This pattern estimates the water consumption for indoor taps and toilets at 40–50 L/p/d.

Pattern F. Four European cities with a frigid climate are included in this pattern: Vienna, Austria; Zurich, Switzerland; Portugal; and Barcelona, Spain. This pattern is the lowest in water consumption among others, with an average water consumption for showering of 30–55 L/p/d, 25–35 L/p/d for toilet use, 10–20 L/p/d for washing clothes, 25–45 L/p/d for taps, and less than 10 L/p/d for kitchens.

As shown in *Fig. 5*, patterns C, D, and E were found to be the highest in water consumption, especially in the cities in the USA, Canada, UAE, and Taiwan, while patterns A, B, and F were the lowest, particularly in European and African cities. Water end-uses of the latter differed in showers and indoor taps and were similar in other activities.

Residential water end-uses for each household activity

Kitchen uses. *Fig. 4* illustrates a decrease in kitchen water consumption in patterns A, C, and F, primarily observed in cities in Australia, Europe, and the United States of America, dropping to less than 10 L/p/d due to the widespread use of dishwashers, which consumed half the amount of water needed to wash the same number of dishes manually (Sadr et al., 2017). Manual dishwashing is typical in Asian societies, especially in developing countries, due to the high prices of dishwashers. This explains the increase in kitchen consumption in pattern B, which includes primarily Asian cities in China, India, Korea, and Vietnam, reaching 20 L/p/d (Makki et al., 2014; Turner et al., 2004). Hug and David (2019) indicated that the low family size and the fast-paced lifestyle of European society, which led to heavy use of fast food or preparing home-cooked meals in small quantities, could be a significant reason for the decline in kitchen end-uses, unlike most Asian societies, which rely on high water-consuming homemade meals in larger quantities. Otaki et al. (2014) argue that food culture can also affect the amount of water used in cooking; for example, rice consumers (as in Asian countries) tend to use large quantities of water in food preparation and washing dishes because of the stickiness of rice in dishes, compared to the amount of water consumed by wheat consumers in European and American society. Patterns D and E have the highest water consumption in kitchens, reaching 20–40 L/p/d in the UAE, Canada, France, Peru, Brazil, and Thailand and increasing to 40–60 L/p/d in Japan and Taiwan. The social characteristics of the population in Peru and Brazil are very similar to those in Asian societies, which explains the similarity of kitchen consumption for both groups (Sivakumaran and Aramaki, 2010). It is worth noting that the cases included in the study did not use treated water in kitchens.

Bathing. As shown in *Fig. 4*, European and many Asian cities in patterns B and F have the lowest bathing water consumption, ranging from 30–40 L/p/d. This consumption increases to 50–60 L/p/d in patterns A and C in Australia and the USA and further rises to 60–80 L/p/d in patterns D in the cities of Thailand, Japan, Brazil, Singapore, Jaipur, India, Sweden, France, and Canada. Several previous studies indicate that higher temperatures are a significant reason for the increased shower consumption in the cities shaping pattern D, which are in hot climate regions (Sadr et al., 20; Shan et al., 2015; Pullinger et al., 2013; Makki et al., 2014). This explains, for example, the higher per capita consumption of bathing in Jaipur (which is one of the hottest areas in India) compared to Haryana, which has a temperate climate, reaching 64 and 30 L/p/d, despite the similar socioeconomic conditions for both cities (Makki et al., 2014). Likewise, bathing consumption in Phoenix, USA, has increased to 60 L/p/d, compared to other American cities in pattern C, due to the high temperatures in southern Arizona, where the city is located (Pullinger et al., 2013). Pattern E is the highest in bathing consumption, with 100 L/p/d in Taipei, Taiwan, and 129 L/p/d in Dubai, UAE, being the highest globally; this may be owing to the widespread tourist housing pattern and higher living standards in these countries, which are directly reflected in water activities, especially bathing (Morote et al., 2016). The water flow rate (high or low) and control pattern (fixed/adjustable) of the bathing fixtures used and the absence/presence of water policies (such as water prices and taxation in cases of exceeding the allowable consumption) are also essential factors for the diversity in bathing water consumption between cities (Roshan and Kumar, 2020). This explains the high consumption of bathing in Canadian and Australian cities compared to European cities, despite the similarity in economic progress and lower temperatures, due to the positive impact of water policies and awareness-raising programs on reducing water consumption in Europe, making it the most efficient in water use in general, including bathing (Matos et al., 2013; Otaki et al., 2008).

Toilet flushing. *Fig. 4* shows a decrease in toilet consumption in patterns A, B, and F, ranging from 20–40 L/p/d, especially in Australian and African cities in pattern A. Low water consumption for hygiene purposes in general (bathing, using the toilet, and taps) has been observed in Africa, reaching only 15 L/p/d in flushing toilets due to the water supply shortages. As a result, consumers carry water from external sources to meet their needs (Samuel, 1986). The consumption increases in patterns D and E, ranging from 40–60 L/p/d, especially in Japan, Thailand, Taiwan, the United Arab Emirates, and Brazil. Winnipeg, Canada, in pattern B, and the cities of the USA in pattern C are the most consuming, reaching 78 L/p/d, despite the economic and technological progress. This may be due to low societal awareness and the absence of an institutional role in reducing consumption (Pullinger et al., 2013). Water consumption in toilets is mainly related to the type of toilet and the water flow pattern (single/double) (Morote et al., 2016). A dual-flush toilet uses about 2.5–4.5 liters of water at a time, half the amount of water used by a single-flush toilet (IPCC, 201). The use of single-flush toilets is widespread in Asian countries such as Taiwan, Thailand, Korea, India, China, Brazil, and Peru, which explains the high water consumption in the toilets of those countries (Otaki et al., 2008; Otaki et al., 2013).

Toilet water consumption is also influenced by consumers' religion and hygiene culture. Arab and Asian societies use more water in toilets than European societies to meet ablution needs and personal hygiene standards (Morote et al., 2016). Some previous studies indicate that the scarcity of water resources in developed countries is a significant factor in the low water consumption of toilets due to the policies pursued by those countries, such as the mandatory installation of low-flow toilets (Troy and Holloway, 2006; Gato-Trinidad et al., 2011). In Japan, for example, the consumption of toilets in the city of Cobi, which suffers from a scarcity of water resources, decreased to 40 L/p/d, compared to the city of Tokyo, which consumes about 60 L/p/d, because of the imposition of the use of low-flow toilets in Cobi City since 1998, until it was circulated to the whole city (Otaki et al., 2014).

Faucets. *Fig. 4* shows a decrease in tap water consumption in patterns B and D, ranging from 10–20 L/p/d, especially noticeable in Japan and European cities. This decline is mainly due to the institutional constraints imposed by the country to reduce water consumption, such as the mandatory installation of sanitary devices and fixtures that consume less water in homes and the imposition of taxes for exceeding the permissible consumption limits (Shan et al., 2015; Otaki et al., 2008; Roshan and Kumar, 2020). In contrast, tap water consumption increases to 30–40 L/p/d in European, Australian cities in patterns A and F and to 40–50 L/p/d in American cities in pattern C and Dubai, UAE, and Taipei, Taiwan, in pattern E due to the spread of detached housing with private gardens in the American cities, using indoor taps to irrigate plants, and the spread of luxury housing in Dubai (Pullinger et al., 2013; Turner et al., 2004). Despite the high economic progress, Sivakumaran and Aramaki (2010) noted that the low levels of environmental awareness may contribute to increased water consumption, especially in indoor faucets. Religious belief can also affect tap water consumption, especially in Arab countries and many Asian countries, where Muslims need more water than other religions due to the frequency of ablution during the day (Morote et al., 2016).

Laundry. Patterns A and E exhibit lower water consumption for washing clothes, ranging from 10–20 L/p/d, especially in Europe, the UAE, and Taiwan. This decline is mainly due to the widespread use of water-efficient washing machines, especially front-loading washing machines that consume less water than other types (Gato-Trinidad et al., 2011; Roshan and Kumar, 2020). Laundry consumption increases less sharply in patterns A and B, ranging from 20–30 L/p/d, due to the increase in family size in Asian countries, especially in Korea, China, India, Vietnam, and Sri Lanka (Fan et al., 2017; Sadr et al., 2017) and the widespread use of traditional water-intensive washing machines due to their low prices (Khattan and Alrawy, 2017). Pattern D shows an increase in laundry consumption, reaching 50 L/p/d in Canada, Sweden, Japan, and Thailand. The highest consumption in American cities in pattern C ranges from 50–70 L/p/d, possibly due to the low family size and lower awareness.

Moreover, laundry consumption is also related to the behavior and routine of washing clothes (i.e., the number of times per week of washing clothes and the amount of clothes per one time), as Arab and Asian societies, especially in developing countries, tend to wash clothes with a whole load of washing machines to reduce the costs. In contrast, consumers in the USA, Canada, and Japan tend to wash clothes in small quantities more often. This may explain the higher consumption of laundry in the last category (Otaki et al., 2008; FAO, 2020). In developing countries with high prices and low incomes, there may be a decrease in the number of washing times and, thus, a decrease in laundry consumption, as in the A and B patterns. Similarly, the lack of water resources has also achieved this in European countries, as in pattern F, increased awareness of water conservation practices may lead to a reduction in laundry consumption from a mental point of view (Rondines-Oviedo and Sarmiento-Pastor, 2020; Khattan and Alrawy, 2017).

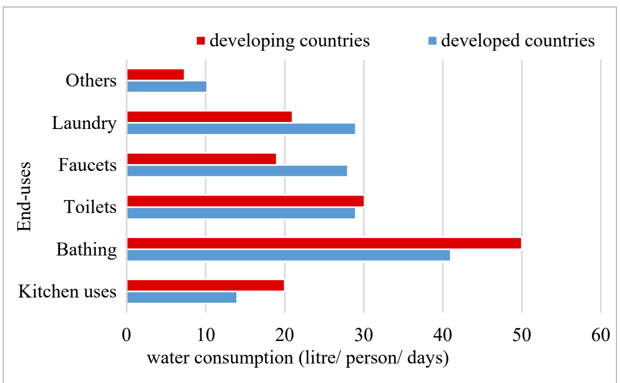
Leaks and others. Water losses are similar among most countries in patterns B, C, D, and E, ranging from 5–10 L/p/d and rising to 20 L/p/d in European and American cities in patterns A and F. Chang et al. (2017) explain that the increased leakage observed in some developing countries can be due to dilapidated plumbing fixtures and a lack of maintenance. On the other hand, Roshan and Kumar (2020) indicate that the spread of detached houses with private gardens in European and American cities and the freezing of water in pipes in some cold regions are significant reasons for the increase in leakage.

Developed versus developing nations' water consumption patterns

Cities included in the study were categorized according to the IMF classification of developed and developing countries for 2002–2023 (World Bank, 2022). *Fig. 6* shows water consumption patterns in developed and developing countries. The researcher calculated end-use values for each category in *Fig. 6* by averaging the per capita water consumption by activity for cities included in each. As can be seen in *Fig. 6*, cities in developed countries use less water in showers and kitchens, at 40 and 14 L/p/d, respectively, compared to 50 and 20 L/p/d for cities in developing countries. The wide use of low water-consuming fixtures and appliances, especially with the purchasing power of consumers, and the adequate water consumption-reducing policies (i.e., the mandatory installation of water-saving sanitary fixtures and smart meters) in many developed countries, particularly in England, Germany, and Singapore, are the main reasons for the low consumption (Pullinger et al., 2013; Makki et al., 2014; Gato-Trinidad et al., 2011). High environmental awareness among consumers and small family sizes also affects water consumption positively (Matos et al., 2013).

However, the cities in developed countries consume more water in indoor faucets and laundry, reaching 28 and 30 L/p/d, respectively, compared to 19 and 21 L/p/d for cities in developing countries. Moroto et al.

Fig. 6. *Water consumption patterns in developed versus developing countries*



(2016) indicate that indoor taps often meet most outdoor water needs in those countries, such as watering gardens, washing cars, etc. The decreased family size and the culture of washing clothes in developed countries are also significant reasons for the high laundry consumption (Turner et al., 2004; Neu Teufel et al., 2014). The water used for toilet flushing is roughly the same for both categories, with an average per capita consumption of 29 L/p/d.

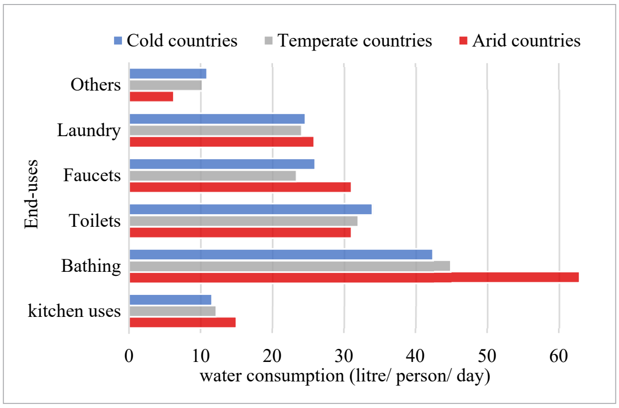
Furthermore, residential WCPs in developed and developing countries are subject to change over time due to changes in water supplies, consumer behavior, policies, and economic and technological development levels. For example, water consumption in the United Kingdom decreased by 50% between 1998 and 2014 due to a significant change in water policies (Neu Teufel et al., 2014; Tingyi and Smout, 2008). Conversely, water consumption in India increased by 35% between 2001 and 2017 due to the change in the social fabric of the population (Bich-Ngoc and Teller, 2018).

Water consumption patterns in different climate regions

Residential WCP also exhibits variations across different climatic zones. *Fig. 7* shows WCPs in three different climatic regions: hot, temperate, and cold. End-use values for the three categories were calculated by averaging the per capita water consumption of the cities included in each. Researchers have noted that temperatures affect water consumption for outdoor activities such as irrigation and swimming pools (Roshan and Kumar, 2020; Chang et al., 2017; Knox and Cutts, 2010). However, the result shows a significant impact of temperatures on water consumption for bathing, with less on toilets and kitchens, where shower frequency of use, duration, and water consumption increase at higher temperatures (Hug and David, 2019; Adams et al., 2013). This could explain the increased consumption of showers in cities with hot climates, reaching 64 L/c/d, compared to 41 L/p/d in cold countries (Otaki et al., 2013; Jiang, 2013).

The impact of climate on the consumption of toilets, faucet taps, and laundry is almost diminishing compared to the economic and social impact because such activities are more related to the type of devices used, personal hygiene culture, and sometimes religion. As shown in *Fig. 7*, the per capita water consumption for toilets remains relatively consistent for the three categories. However, toilet usage frequency and thus consumption

Fig. 7. *Water consumption patterns in different climatic regions*

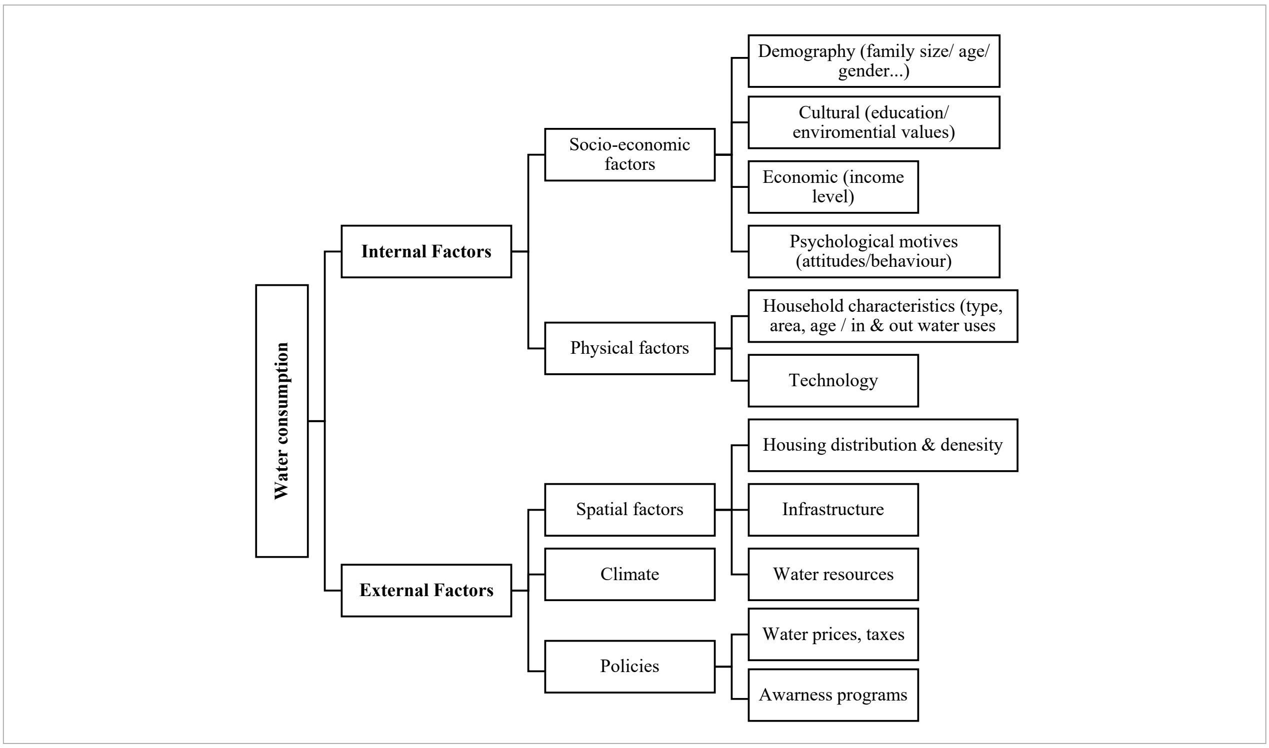


increase in cities and countries with lower temperatures (Shan et al., 2015), ranging from 31–34 L/p/d. Water consumption by faucets increases in hot climate countries (such as India, Colombia, and Peru), reaching 31 L/p/d due to water intensive appliances. It also increases slightly to 26 L/p/d in countries with cold climates (such as Austria, Switzerland, the Netherlands, and Colorado, USA) due to the use of indoor taps for outdoor garden irrigation, as mentioned earlier (Pullinger et al., 2013; Turner et al., 2004). There is no noticeable effect of climate on laundry consumption because it is mainly related to the basic needs of consumers, the washing routine, and the type of washing machine used (Otaki et al., 2008; Khattan and Alrawy, 2017).

Factors affecting residential water consumption patterns

Household water consumption is subject to many factors, including socioeconomic aspects, household characteristics, climate, policies, and spatial factors. The multi-analyses of residential end-uses presented in sections 3-2, which examined the residential water consumption patterns globally, revealed the impact of some of these factors on the various water activities. Further, several studies have examined some theoretically. This section provides a comprehensive view of these factors, synthesizing the main findings. The research classified the influencing factors according to their type of effect into internal factors, which are more related to consumers and affect water end-use directly (such as age, income, number of inhabitants, and household type), and external factors, which have an indirect impact on water end-uses and are not controllable by the consumer, such as urban pattern, infrastructure and water supplies, climate, and water policies. *Fig. 8* shows the contextual influencing factors, and they are briefly described below.

Fig. 8. *Classification of factors/variables affecting household water consumption*



Internal factors

Socioeconomic factors

Household dynamics are fundamental to understanding the environmental impacts of using natural resources, including water (Bradley, 2004). Family size, which indicates the number of people living in a household, influences water consumption differently. In principle, the more people live in the house, the larger the aggregate demand is supposed to be (Hug and David, 2019; Oduro et al., 2018; Kumar et al., 2020). This finding is also proven by Willis et al. (2011), who observed that one person's increase in family size leads to a decrease in total household consumption by 4.05 m^3 due to consistent water usage for activities such as dishwashing and laundry, regardless of family size. Nonetheless, economies of scale for water optimization are generally not achievable in small households, as an optimal family size exists; beyond this limit, these economies of scale tend to vanish (Bradley, 2004). The results of the comparative analysis confirmed this theory, showing a decrease in per capita consumption with increased family size, especially in Asian cities.

The age structure of a given family, such as the number of adults and adolescents and the presence/absence of children/elders, is also a closely relevant driver of household water consumption (Hug and David, 2019; De Oreó and Mayar, 1999). According to Hug and David (2019), elderly family members consume less water than younger adolescents and youth, especially with the high-water prices. Families with children or teenagers are expected to use more water generally, especially for taps and outdoor uses (Samuel, 1986; De Oreó and Mayar, 1999). For example, water consumption in Lima, Peru, has increased by 2.75% for families with children (Tingyi and Smout, 2008).

Education and cultural levels are related to environmental awareness (Willis et al., 2011). Regarding water, this can be translated into purchasing water-conserving devices or planting drought-tolerant garden species (Al-Sumati et al., 2020; Rondines-Oviedo and Sarmiento-Pastor, 2020). However, several studies have indicated a gap between consumers' awareness and their actual behavior in preserving water (Turner et al., 2004; Tingyi and Smout, 2008). Psychological drivers of using water, such as lifestyle and attitudes, also indirectly affect water consumption (Otaki and Otaki, 2017). These motives have resulted from the strong development of personal water use habits, as in religious practices such as ablution or personal hygiene culture (Pullinger et al., 2013). However, developed countries' water policies, such as pricing mechanisms and awareness campaigns, have successfully changed several water use habits (Neu Teufel et al., 2014).

Household income is the most studied variable influencing household water consumption (Otaki et al., 2013). It is widely accepted and empirically proven that household water consumption positively correlates with income. Higher-income families tend to have larger houses with more luxurious sanitary facilities, green areas, and swimming pools, which results in higher water consumption (Pullinger et al., 2013; Rathnayaka et al., 2015; Troy and Holloway, 2006). However, some studies propose that higher-income families may use less water due to the higher purchasing power required to have more water-efficient devices (Sadr et al., 2017; Hug and David, 2019). Nevertheless, Al-Sumati et al. (2020) have pointed out that this theory can often be affected by people's resistance to changing their habits, even if the ability to buy high-cost smart devices is available.

Physical factors

Household characteristics, often included in the literature, are the building's type, size, age, and indoor and outdoor water use activities. Housing type is significantly connected to water use, both indoors and outdoors, and is usually related to household income (Bich-Ngoc and Teller, 2018; Pullinger et al., 2013; Fan et al., 2017; Matos et al., 2013). Oduro et al. (2018) have classified houses based on the number of bedrooms and the presence of gardens and/or swimming pools into four types (residential complexes, apartments, semi-detached, or detached houses). Higher water consumption was observed for large, newer, higher-value houses with more bedrooms and gardens, i.e., semi-detached and detached houses, while apartments were the most responsible for water use. This may be due to the fact that sanitary fixtures used in new houses usually consume more water than traditional fixtures in old houses (Sadr et al., 2017; Shan et al., 2015).

On the other hand, the presence of external water uses, i.e., gardens and swimming pools, is positively correlated with family income and lot size (Fan et al., 2017; Matos et al., 2013) and negatively correlated with urban density (De Oreó and Mayar, 1999). Houses with swimming pools, on average, use twice as much water as houses without swimming pools (Bich-Ngoc and Teller, 2018). Garden consumption accounts for nearly 30% of total household consumption in Barcelona (Spain) and 40% in England (UK) (increasing to more than 50% during the summer) (Butler and Memon, 2006). External water uses are usually related to luxury activities; thus, they are more susceptible to seasonal and price changes (Bich-Ngoc and Teller, 2018).

Water technology, such as high-efficiency fixtures and appliances (low-flow shower heads and taps, dual-flush toilets, pressure reducers, etc.), and micro-measurement have an essential role in shaping water consumption patterns (Gato-Trinidad et al., 2011; Yao, 2013(, besides being effective solutions to save water, compared to the cost of water recycling or desalination (Bich-Ngoc and Teller, 2018). For example, a traditional shower head uses an average of 20 liters/minute, while a low-flow shower head only uses 8 liters/minute, and a water-efficient washing machine uses about half as much water as a regular wash (Park and Jeong, 2012). According to Fan et al. (2017), upgrading traditional home fixtures and appliances with more efficient ones can reduce total water consumption by 35–50%. Moreover, micro-measurement using smart meters gives people real-time measurements of the volume of consumed water by internal and external end-uses (Khattan and Alrawy, 2017) and detects locations of possible water leakage in the house (Mead and Aravinthan, 2009). Tracking consumption can reduce 20–40% of the total water consumption due to the psychological impact of monitoring personal consumption and the fear of a high water bill (Chowdhury et al., 2015). The expanded use of smart meters could help raise awareness, change user behavior (Otaki et al., 2008), and test the effectiveness of other demand management procedures, especially prices (Otaki and Otaki, 2017).

External factors

Spatial factors

Understanding how people settle spatially is critical to comprehending the changes in urban water consumption (Gato-Trinidad et al., 2011). Housing distribution patterns, i.e., compact or dispersed, in an urban community can significantly change per capita water consumption (Hug and David, 2019), as well as are directly related to house type, family size, income, and water use behavior (Kumar et al., 2020). Generally, high urban density in the compact pattern positively affects per capita water consumption through smaller lot sizes and outdoor space (De Oreó and Mayar, 1999; Gato-Trinidad et al., 2011). This may explain the significant disparity in residential water consumption between the United States (340 L/p/d) and Europe (136 L/p/d) despite the similar socioeconomic characteristics, due to the broader presence of detached and semi-detached houses in a dispersed urban form with lower density in the USA, compared to the higher density found in Europe (Hug and David, 2019).

The efficiency of infrastructure networks and water supply affects total water consumption (Sadr et al., 2017). For instance, in Nairobi, due to poor water supply, the combined consumption of the kitchen, toilets, and bathroom is only 45 liters/year, making it the lowest in the world (Samuel, 1986). Additionally, per capita consumption increases in areas with high and stable water pressure and decreases in others with low water pressure, such as in new cities or suburban cities in Egypt (GOPP, 2011). However, high water pressure may cause explosions in pipes and thus increase leakage levels and total water consumption (Sadr et al., 2017).

Water resources, such as river surface, seawater desalination, or groundwater, may also affect household and per capita water consumption, especially for end-uses like kitchens, faucets, and showers. For example, indoor water consumption for kitchen use may decrease in coastal cities, compared to Delta cities, due to limited freshwater resources and the dependence of many residents on external sources for drinking and cooking.

Climate

Temperature and rainfall are among the most explanatory climatic drivers of residential water consumption (Hug and David, 2019). Hot climates increase garden watering, swimming pool use, and personal hygiene, such as drinking and bathing (Rathnayaka et al., 2015; Bich-Ngoc and Teller, 2018). This phenomenon is attributed to the increased evapotranspiration from both humans and plants, which increases their need to be hydrated and higher evaporation rates in swimming pools, with the subsequent need to be filled frequently (Hug and David, 2019). This could explain the higher water consumption rates in hot countries such as Brazil, the UAE, and India. However, the effect of high temperatures varies according to urban patterns; while the increased water consumption in low-density areas is mainly concentrated in outdoor uses, it is limited to indoor water consumption, especially bathing, in areas with high density (Puvanisha et al., 2020). Rainfall is also expected to influence outdoor activities, especially garden watering in cold countries (Hug and David, 2019). Despite this, Kumar et al. (2020) have indicated that rainfall may have a dynamic and non-linear effect on initial water demand, but it has diminished over time.

Policies

Water policies, including water prices, taxes, subsidies, and consumption campaigns are used to reduce water consumption (Al-Sumati et al., 2020). Water prices are the most essential and common mechanisms influencing water consumption, which makes sense if water is treated as a purely economic commodity (Puvanisha et al., 2020). However, several studies have demonstrated that the price elasticity of water demand varies depending on the activity. This means that the more essential the use, such as drinking, cooking, and personal hygiene, the lower the price elasticity for this activity, i.e., nearly zero. In contrast, for recreational or non-essential activities such as garden irrigation, swimming pools, or bathtubs, price elasticity is approaching one (Adams et al., 2013; Grafton et al., 2011; Willis et al., 2011). Income dramatically affects the response to price mechanisms (Morote et al., 2016). According to Abou-Rayan (2016), high-income families enjoy more stable and flexible water consumption patterns relative to price, meaning that they do not respond efficiently to price changes compared to low-income families, especially older consumers. Rondines-Oviedo and Sarmiento-Pastor (2020) also suggest that these mechanisms should be accompanied by changes in tax regulations and financial incentives to achieve the desired effect.

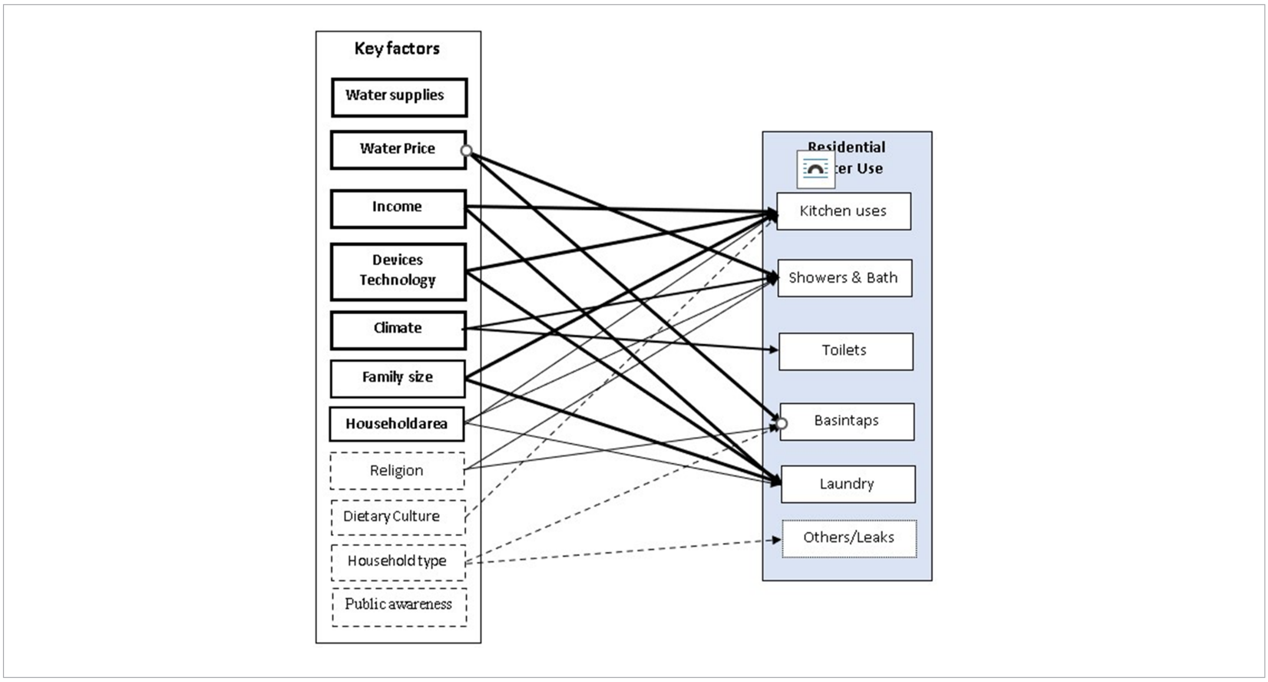
Table 4 generalizes the effects of each factor or driver on increasing and/or decreasing water consumption. Conclusive effects for each household activity are presented in *Fig. 9*.

Table 4. *Generalized factors and variables that explain increases and decreases in household water consumption*

Factors	Variables	Impact on water consumption
Socio-Economic Factors	⇧ Number of inhabitants[1]	+ / –
	⇧ Age structure	–
	Gender	+ / –
	⇧ Number of workers	+
	⇧ Education[2]	–
	⇧ Environmental value[1]	–
	⇧ Household income[3]	+ / –
	Attitude and behavior	+ / –
Household characteristics	Housing type[2]	+ / –
	⇧ Lot size[2,3]	+
	⇧ Household area[2]	+
	<Building age	+ / –
	⇧ In and out water usage[2,3]	+
	Devices technology[2,4]	– / +
	Micro-measurement	–
Spatial factors	⇧ Neighborhood density	+ / –
	Housing distribution pattern[2,3]	+ / –
Infrastructure	⇧ Water supplies[4]	+
	⇧ Water pressure[4]	–
Climate	⇧ Temperature	+
	⇧ Rains/drought	+
Policies	⇧ price structure[2,4]	–
	⇧Taxes[4]	–
	Rising awareness programs	–

Notes:
(+) = increasing of water consumption;
(–) = decreasing in water consumption;
1 = correlation with education;
2 = correlation with income;
3 = correlation with housing type;
4 = depends on water restriction regulations.

Fig. 9. *Key factors influencing each residential activity*



Notes: Correlations range from highly correlated (in bold) to less correlated (non-bold, dotted line).

Potential water consumption patterns in Egyptian cities

Given the uniqueness of Egyptian society and the results of the comparative analyssis of currents trends in water consumption patterns presented in section 3-1 "Distribution of end-use studies "and section 3-2 "Residential water consumption patterns around the world", it is expected that Egypt's home water consumption patterns will align closely with pattern D. Water consumption is predicted to be high for kitchen uses, showers, and toilets, with average consumption for laundry. However, it might differ and be higher for faucets. This is due to the low-cost, water-intensive fixtures installed in most Egyptian homes, with the potential to increase the frequency of use to meet Muslims' need for ablution during the day, particularly for people working longer hours. The increased consumption of laundry and kitchen might be due to the tendency of most Egyptian families to wash clothes with a whole load of a washing machine to reduce costs, prepare home meals, and wash dishes manually due to the high prices of dishwashers. However, it is essential to note that these expected patterns may vary according to Egypt's different environmental and urban patterns and their different climatic, urban, and social characteristics. For example, kitchen water consumption may decrease in coastal cities due to the limited freshwater resources, with residents using external portable water to meet their needs for drinking and cooking. Conversely, it may increase in Upper Egypt cities due to the high family size and high temperatures.

The study has also suggested several vital factors that are thought to affect residential water consumption in Egyptian cities and should be considered in future studies:

Socioeconomic factors. It is assumed that the low income for most families, particularly with the current increased water prices, may reduce water consumption, despite the use of non-water-saving appliances. However, this assumption may conflict with the influence of cultural and physiological factors on water use.

Water policies. Current water reduction policies, such as water prices or prepaid smart meters systems, which the Egyptian government has already implemented as a plan to be adopted in new and existing cities, rather than the prevailing practice system, could potentially affect water end-uses, particularly for low-income families.

Spatial factors such as housing patterns, climatic conditions, water resources, and water supply efficiency differ according to Egypt's environmental and urban patterns.

Consumers' health information should also be included in data collection due to the current widespread diseases in Egyptian society, such as diabetes, which may increase water use, especially for toilets and drinking water.

The research also recommends using the methods of observation, questionnaires, and interviews for collecting data, deemed more appropriate to the privacy of Egyptian society, compared to the more accurate methods like flow rate measurements using smart meters, which Egyptian families may reject due to their high prices and unavailability in Egypt.

Conclusions

Urban water demand in Egypt is estimated based on annual average consumption and urban classification of cities without considering differences in environmental and urban patterns that influence water use behavior and consumption rates at the household level. This lack of understanding of how water is used in homes and why has led to a decrease in the effectiveness of current water demand management strategies. Therefore, specific location-based research is required to understand how water is used at homes and improve WDM efficiency by understanding where and how to use it. Water consumption patterns studies provide accurate and realistic data on household water consumption in a particular city/urban area by estimating water end-use for activities such as cooking and bathing and reveal key factors that affect household water consumption such as family size, income, house type, and device technology.

Previous studies have often focused on specific cities/countries and only examined one/few influencing factors, failing to understand all potential patterns and factors comprehensively. Therefore, the present study aimed to develop a theoretical/conceptual framework for different residential water consumption patterns worldwide and their shaping factors by conducting a comparative analysis of available end-use data and identifying trends, variations, and correlations in how people with varied backgrounds use water. This can help fill the current gap and provide a tool for data collection in Egyptian cities and a nucleus for global research.

The study documented and analyzed water end-use data in 39 major cities in different climatic and socio-economic conditions across developed and developing countries. The results reflected a complex picture of worldwide trends and possible factors, summarized in three parts:

1 Worldwide trends in water consumption patterns. Six major worldwide trends in WCP were identified: Pattern (A) is characterized by average water consumption for all activities with a maximum consumption of 40–60 L/p/d in bathing, and seen in major cities in Australia, China, Sri Lanka, the Netherlands, and Central Africa. Despite the differences in location, climate, and socioeconomic characteristics, the similarity in water usage between these cities can be attributed to the significant effects of water policies and water supplies. Pattern (B) exhibits the lowest water consumption, particularly in bathing and taps, to reach 25–40 and 10–20 L/p/d, respectively, and is most common in Asian cities in developing countries such as Harney and Hebei. Pattern (C) shows the highest water consumption, especially in toilets and laundry, reaching 60–80 and 50–60 L/p/d, respectively, and is concentrated in major cities in different states in the USA. Pattern (D) has high water consumption in bathing to 60–80 L/p/d and varies in the kitchen to range within 20–50 L/p/d, and is found in cities in Europe, Asia, Canada, and South America that are different climatically, economically, and socially. Pattern (E) is less common and includes cities like Dubai and Taipei, where bathing consumes the most water due to luxury housing, reaching 129 L/p/d in Dubai, while laundry is the least, reaching 10–20 L/p/d. Pattern (F) represents, in particular, European cities with cold climates, such as Vienna and Zurich, with low water consumption for all activities.

2 Factors influencing water consumption. Residential water consumption can be influenced by many factors/variables such as family size, income, water price, education, culture, housing characteristics, technology, climate, and policies. Geography (water resources and climate), culture, and policy were important for explaining consumption in developed

countries, while economic factors (income and water prices) and socio-demographic variables were critical in developing countries. All these factors reveal a very complex and dynamic picture with many possible interrelationships. Thus, the effect of one variable is hardly independent of the effect of others, which in turn may affect the consumption rate of a given society. For example, changes in water policies can affect physiological drivers to reduce consumption, such as water usage behavior. Also, family income affects household type, area, and water efficiency technology choices. Significant correlations were found between factors and water end-use, such as the number of children and increased use of basins; higher income and increased use of washing machines; water prices; and decreased use of bathing and taps. These correlations pose challenges for researchers in choosing suitable modeling techniques with the most influential factors to avoid autocorrelation.

3 Potential patterns of residential water use in Egyptian cities. Given the uniqueness of Egyptian society and the research findings, the overall water consumption pattern in Egyptian cities is expected to be high for activities such as kitchen use, bathing, and faucets and average for toilets and laundry. However, these patterns may vary depending on the region's environment, urban form, and social characteristics. Future studies in Egypt should consider socioeconomic factors, water policies, supply efficiency, and consumer health as crucial factors influencing water consumption. Understanding water use patterns for different socioeconomic groups is the first step to profiling residential water consumption in Egypt. This can help develop different spatial models of water consumption within the city that could be used as a new tool for urban planning and sustainable management of water resources and suggest water conservation solutions for targeted areas.

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Appendix A

Table (2). *A comparative analysis of the residential indoor water end-use studies across different cities in continent-wise distribution*

Cities/Countries		Year	House-hold surveyed	Person/ household Kitchen uses	Indoor water end-use*						Total indoor water con-sumption*
					Bathing	Toilet flushing	Taps and cleaning	Washing machine	Others		
Asia	China, Beijing	2003	40	3	7.1	42.4	26.9	21	22.5	4.6	104
	China, Hebei	2003	NA	NA	14.9	23.7	30.0	14.2	27.3		138
	China, Harbin	2017	NA	NA	17.5	36.6	33	23	25.4		135.8
	South Korea	2006	146	NA	18.4	40.1	38	10	30.8	3.5	141.3
	UAE, Dubai	2013	100	NA	34	129	49	46	20		278
	Thailand, Chiang	2004	63	NA	13	78	52	14	42		147
	Vietnam, Hanoi	2011	56	NA	10	30.4	28.3	25.7	16.2		70
	Singafora	2016	NA	NA	23.7	57.7	26.6	59	22.2	8.9	148
	India, Haryana	2011	763	NA	23	29	27	30	32	8	149
	India, Jaipur	2017	100	5.1	31.6	63.7	45.8	31.8	17.9	5.6	199
	Colombia, Sri Lanka	2004	20	NA	10	37	29	23	21	10	110
	Tokyo, Japan	2010	NA	NA	60	64	58	10	49	8	250
	Kobi, Japan	2007	NA	NA	50	68	40	20	50	6	234
Europe	Hamburg, German	2012	NA	NA	18	30	40	10	20	8	126
	Cambridge, England, UK	2004	NA	NA	10	36	35	10	19.5	18	150
	Vienna, Austria	2012	103	NA	8	29	24	26	14	22	138
	Swizarland	1999	NA	NA	9	22	28	35	20	9	163
	Netherlands	2007	NA	NA	8	43	27	20	16	10	129
	Portugal	2011	52	NA	8	57	33.7	43.3	11.8	13	147
	Span, Barcelona	2016	NA	NA	10	44	34	37	12	20	117
Australia	Perth	2000	120	3.3	4.47	52.2	32.6	24.8	21.9		155.2
	South Wales, Sedney	2002	NA	NA	10	59	35	29	29	13	184
	Victoria, Melbourne	2004	100	NA	10	61.5	32	26	31	45	115
	Victoria, Melbourne	2011	NA	3	15	61,5	22	35	31	45	210
	Queensland, Gold Coast	2008	NA	NA	2.2	52.6	20.9	26.6	30	1.8	143.1
	Queensland, Brisbane	2015	210	2.65	3.9	40.5	20.4	21.9	36.2		107.4
	New Zealand, Auckland	2006	12	NA	5.1	50.4	31.3	22.7	29.9	7.8	154
South America	Peru, Lima	2019	900	NA	21	40.7	30		11.9	15.8	105
	Brazil, Florianopolis	2003	20	NA	17	73.3	47.9	23.3	16.4	10	180
North America	San Francisco, California, USA	2018	NA	2,77	10	60.2	37.7	42.7	43.2	10.0	200.0
	Boulder, Colorado, USA	2017	900	2,59	8.5	60	62	38.4	62	12.6	201.15
	Denver, Colorado, USA	2017	NA	4	7	46	58	49	33	6	244
	Phoenix, Arizona, USA	2017	NA	NA	9	60	77	50	66	10	291
	Tampa, Florida, USA	2017	NA	NA	5	40	68	50	49	10	
	Atlanta, Georgia, USA	2017	NA	NA	7	45	71	54	44		
	Winnipeg, Canada	2011	NA	NA	25.1	67.9	30.3	42.6	50.2	10	251
Africa: Kenya, Tanzania and Uganda		2001	5510	2-4	10	64	58	49	33	32	125

* Liter per person per day

Appendix B

Fig. 3. *Distribution of water consumption patterns included in the studies, clustered by similar patterns*