Lessons Learned for Drought Cities: Promising Steps towards Water Sensitive Urban Design in Arid and Semi-arid Cities

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Abstract

Water security is one of the main challenges facing urban areas in arid or semi-arid zones. Egyptian cities need to deal with both insufficient quantity and quality of water for residents. Here we provide proposed actions and policies to allow transition towards water sensitive urban design in order to respond to water challenges in Egypt. Based on a systematic literature review, we have selected a set of criteria concerning the environmental, economic, social, governmental, and infrastructural dimensions of urban water management. We compiled and compared management approaches from Lima, Windhoek, and Adelaide. The three cities have climatic conditions and water issues similar to Egyptian cities and have made substantial advances towards sustainable water management. We then evaluated which elements can be adapted and used in Egypt. Proposed actions included participatory approaches that engage the community in water management, educational campaigns that lead to change of public perception, and assessment of water services through customers' satisfaction.

Highlights

- A top-down approach is essential for the transition to integrated water management.
- Including the public in the water services provision process increases access to water services.
- Raising public awareness plays a major role in acceptance of new water management approaches.
- Knowledge availability about water services and challenges for all stakeholders allows integrated solutions and decision-making process.

1 Introduction

The world water crisis is not too little water to satisfy human needs, but about bad water management (Sen, 2013). Mishandling of water resources increases the challenges of water pollution, floods, and water shortage (Maksimovic et al., 2015). Rapid urbanization leads to reduced freshwater resources due to higher demands, increased amounts of wastewater produced, and reduced ground water recharge (Pereyra, 2015). It is estimated that, by 2025, 1.8 billion people will be living in areas facing absolute water scarcity. Approximately two-thirds of the world's population are expected to suffer from water stress by the same date, and about 24–700 million people are expected to be displaced due to water scarcity in arid and semi-arid places (UN, 2014).

Egypt, an arid developing country, with 99% of its population concentrated in the urban agglomerations of the Nile Delta and Valley, has already passed the water scarcity threshold (1000 m^3/capita/year), and is predicted to reach the threshold of absolute scarcity (500 m^3/capita/year; Seada et al; 2016). Compounding the situation, large amounts of untreated wastewater are discharged into the Nile River, the Mediterranean Sea and local lakes (e.g., Manzala and Mariout; African Economic Outlook, 2016). In addition, the redistribution of people to new cities will pose more pressure on local water resources. All these underscores the need for new water management approaches (Abdel-Fattah et al., 2015).

Here we aim to develop a guiding framework for transition from the current conventional urban design in Egyptian cities to a water sensitive approach adapted to the local context and challenges. To do so, we adopt the concept of Water Sensitive Urban Design (WSUD) (Sharma et al., 2016; Hoyer et al., 2011) to arid and semi-arid cities. WSUD is a holistic approach to urban planning and design that integrates the management of the whole urban water cycle into the process of land use and urban development. In WSUD, urban water is managed so that it minimizes the negative urbanization impacts while maximizing the economic, social, and environmental benefits, thus providing more healthy and livable cities (DEWNR, 2013).

In arid and semi-arid areas, WSUD is a cost-effective approach for managing already scarce water resources and brings many benefits. Efficient use of water resources, for instance, allows creation of green open spaces through treated wastewater, and using native plants consumes little water. Green open spaces are critical in these regions, as they mitigate the extreme heat, provide urban cooling, and improve thermal comfort. Such spaces can be multifunctional, providing, in addition to water management solutions, ecological, social and amenity benefits. WSUD practices can also increase storm water infiltration and recharge of groundwater, which help in drought adaptation. The challenges of implementing WSUD in arid and semi-arid regions include health risks of water reuse in green areas and water surfaces, public acceptance and lack of experience and knowledge. In addition, in densely populated areas, the need for large spaces to implement water sensitive solutions is a challenge, and institutional barriers also hinder the wide application (Costa, et al; 2015).

We reviewed experiences of successful implementation of WSUD in arid and semi-arid cities (Lima, Peru; Windhoek, Namibia and Adeleide, South Australia) to examine their water management approaches. All three cities have climatic and water conditions similar or close to Egyptian cities. Lima, which has a desert climate and is considered the second driest capital of the world after Cairo (Egypt), has undertaken efforts of transition to a sustainable water management system and green infrastructure (Carroll, 2017; Barrett, 2017). Windhoek, facing drought and water shortage, is the first city in the world to treat wastewater for safe drinking water, and has successfully raised public awareness and acceptance (Lahnsteiner and Lempert, 2007; African Water Facility, 2017; Scott et al., 2018). South Australia, the city of Adelaide has faced many droughts, including the Millennium Drought (2001–2009), which severely impacted the water quality of the River Murray and caused flooding. Consequently, the city is currently in the process of transition towards a water sensitive management of its water cycle (Government of South Australia, 2010, 2014).

Here we (i) present the set of criteria to analyze WSUD approaches in the cities, (ii) compare the different approaches, and finally, (iii) provide recommendations for the transition of Egyptian water management towards a WSUD.

2 Material And Methods

2.1. Criteria Selection for comparative Assessment of Case Studies

A systematic literature review was carried out to identify a set of criteria for analyzing water management approaches in arid cities. Using the Web of Science database with the keywords ‘sustainable urban water management' OR 'water sensitive cities' resulted in 1980 papers. These were then restricted to reviews, resulting in 126 reviews since 1992. All the reviews were carefully analyzed. Selection of criteria (Fig. 1) was based on the three components of sustainability (economic, environmental, and socio-cultural dimension) as the most common categories used to account for cost and benefits of water planning decisions. The transition to sustainable urban water management requires collaborative efforts among all stakeholders (UN, 2010). Governmental power and will are required to induce and mainstream changes, thus we also included the ‘governance dimension’ to consider the institutional system that holds and integrates the other components within the overall framework. In addition, since decisions on urban water infrastructure are regularly influenced by physical constraints, we included the ‘physical dimension’ (Rathnayaka et al., 2016).

The environmental dimension includes climatic parameters that directly determine specific local vulnerabilities and risks (Bertule and Forenede Nationers Miljøprogram, 2017). It also includes topographical criteria to determine the convenience of certain water management approaches and solutions (Tkach and Simonovic, 2002); ecological criteria to indicate biodiversity, protected areas, and disasters; water quantity to indicate the total amount of water available for human and ecosystem uses (Shilling et al., 2015) and water quality to describe the safety requirements for wastewater reuse and control, pollution sources and quality of waterbodies (European Commission, 2000).

The social dimension of water management includes population characteristics, which are directly linked to water demands; education, which is a key factor in irrational water uses and unsafe waste disposal; poverty, which is associated with the availability of agricultural water (Hussain et al., 2003); population health which impacts childhood mortality from water-related diseases (World Health Organization, 2009); public awareness, which is key in new water management solutions (Kitamura, et al., 2014); equity which describes the extension of basic water and sanitation services to the unserved and underserved poor; and water access to households, which determines their capacity to adopt hygienic behavior and co-operate in measures for the control of water-related disease (European Commission, 2000).

The economic dimension illustrates the flow of capital and the main economic impacts associated with water supply and demand management (Rathnayaka et al., 2016). It includes financial viability which ensures continuity of financial support to water solutions; and water fees, which influences the use of water and selection of water sources (Hiroki Koetsier, 2004).

The governmental dimension includes stakeholders involvement, to ensure long-term commitment of management practices over different sectors; public participation, to allow a shared decision-making process and promote a sense of responsibility; ownership to increase commitment and improve the relationship between the public and private sectors; knowledge availability to allow the identification of risks and technologies and to reach scientifically informed decisions (Ferguson et al., 2013); integrated policies to determine water demand management measures, including water tariffs, pollution charges, leakage control and restrictions.

The physical dimension includes urbanization rates, which require additional water resources; green spaces which provide a wide range of ecosystem services such as habitat services for species, and protection of soil and water quality; and water infrastructure types which need to be selected according to efficiency, appropriateness, cost, and potential for adaptation to the local environment and future changes (European Commission, 2000).

Figure 2 shows the relation between the five main dimensions and WSUD, while showing the selected criteria of each dimension. The font size determines the relevance and importance of each criterion. Larger font size indicates that the criterion is more important and relevant to the transition process towards WSUD, while smaller font size indicates relatively less importance and relevance.

2.2. Analysis of stakeholders and water management approaches

The organizations and stakeholders in each of the case studies and in Egypt were studied based on their roles and responsibilities in water management. After studying the water management approaches in the case studies, in addition to studying the context and water management of Egypt, we selected approaches that can address the main water challenges in Egypt.

Next, we arranged the stakeholders in Egypt to identify those of high influence in the decision-making process. Finally, we carried out interviews with representatives from key institutions in the water sector in Egypt, to get their feedback based on their real-life experience. Each representative was asked to evaluate and give their feedback to the suggested policies and actions, and their applicability in Egypt. We used their input and suggestions to develop the proposed policies and actions to allow transition of Egypt to a water sensitive management approach.

3 Results

We summarized the collected data for the environmental and physical dimensions of Lima, Windhoek, Adelaide, and Cairo (Table 1). All cities share challenges of water quantity and quality, along with vulnerability to climate change. The cities also face desertification, which affects water availability by decreasing the water storage ability of the soil and loss of runoff water that could have been used in dry seasons. Figure 3 provides maps of the studied cities, showing water resources and water treatment plants.

Table 1
Summary of selected environmental and physical context of Cairo (Egypt), Lima (Peru), Windhook (Namibia) and Adelaide (Australia).

Sources of data: ClimateData, n.d[1]; Zumaran, 2006[2]; Callañaupa et al., 2018[3]; Shikangalah, 2016[4]; Lahnsteiner and Lempert, 2007[5]; Gerges et al., 2006[6]; El-Sayed Hassan, 2013[7]; MediaCompany, 2014[8]; Shikangalah, 2016[9]; KPMG, 2009[10]; Adel et al., 2012[11]; Vilcara and Karina, 2009[12]; Namibia Environmental and Climate Change Policy Brief, 2008[13]; Government of South Australia, 2003[14]; World Population Review, 2019[15]; Carroll, 2017[16]; Population Australia, 2019[17]; Castro et al., 2011[18]; Rensburg, 2006[19]; Government of South Australia, 2013[20]; EPA, 2016[21])

		Criteria	**Cairo (Egypt)**	**Lima (Peru)**	**Windhook (Namibia)**	**Adelaide (Australia)**
Environmental	Topography Climate	Classification	Bwh	Bwh	BSh	Csa
		Temperature	21.3°C[1]	18.5º C[2]	18–20 ˚C[4]	16.4°C[1]
		Precipitation	18 mm[1]	5.9 mm[2]	370 mm[5]	531 mm[6]
		Vulnerability to Climate Change		Increased Droughts and Water Scarcity[9,10]		
			Decrease of Rainfall[7,8]		Increasing temperatures[9,10]	
			Sea level rise leading to flooding and low food production affecting economy[7]	Melting of the Andean glaciers and economic threats[8]	Variable rainfall patterns[9]	Decrease of rainfall; drying of aquatic ecosystem; changes in the water regime to ephemeral[10]
		Main Land Use	Agriculture	Residential	Agriculture	
		Biodiversity	Biodiversity contributes to economy	Peru among top 10 biodiverse countries	Namibia is an international biodiversity hotspot	Diverse landscape leads to variety of ecosystems and species
	Ecology	Degradation	Prone to sea water intrusion into ground water[11]	Desertification and erosion, affecting the availability of water[12,13]		River and dryland salinity[14]
		Disasters	Rockslide and heavy rains flooding roads	El Niño Costero; flooding; landslides Extreme droughts		Extreme droughts
Physical	Urbanization	Urbanization Rates	Urban population represents 43% in Egypt[15]	Urban population represents 78% in Peru[16]	Urban population represents 49% in Namibia [5]	Urban population represents 86% in Australia [17]

		Criteria	Cairo (Egypt)	Lima (Peru)	Windhook (Namibia)	Adelaide (Australia)
		Urban growth	1.9% [15]	1.5% [16]	4.3% [5]	1.7% [17]
	Infrastructure	Type	Dam, reservoir and treatment plants[18]	Reservoirs, water treatment plants[19]	Dams and reservoirs, boreholes for groundwater extraction.	Reservoirs, water treatment plants[20]
		Efficiency	Insufficient wastewater treatment, high leakage levels and low levels of household metering[12]	Weak continuity, high breakage and above average water loss rates [19]	Average leakage in households, old infrastructure that doesn't cope with the increasing population	Water main renewals resulted in lowering breakage rates due to improvement efforts[21]

Table 2
Summary of the comparison between the three case studies according to the environmental, social, economic, and governmental dimensions (By Authors, data from Carroll, 2017[1]; Carreazo et al., 2006[2]; Scott et al., 2018[3]; Uhlendahl et al., 2010[4]; Crovello et al., 2010[5]; Boucher et al., 20116; Government of South Australia, 20137; Jaeckel, 20148; KPMG, 20099; Chubaka et al., 201810; Australian Government, 200311; Instituto Nacional De Estadistica E Informatica, 201712; CIA, 201813; ACAP, 201714; Simon, 201815; Hommes and Boelens, 201716; Vilcara and Karina, 200917; Rensburg, 200618; Lahnsteiner and Lempert, 200719; CIA, 201920; Namibia Statistics Agency, 201421; Government of Namibia, 201522; Population Australia, 201923; SA Planning Portal, 201824; Worldatlas, 201825; Australian Bureau of Statistics, 201726; EPA, 201627; Australian Bureau of Statistics, 201128; Office for Water Security et al., 200929; Kgabi and Mashauri, 201430; Miranda Sara and Baud, 201431; Simon, 201832; Ioris, 201633; Felgendreher and Lehmann, 201234; Kastner et al., 200535; Flod and Landquist, 201036; South Australia Council of Social Services, 201737; SAWater, n.d.1; Calzada et al., 201739; Castro et al., 201140; Liehr et al., 201841; Keremane et al., 201742)

		Criteria	**Lima (Peru)**	**Windhoek (Namibia)**	**Adelaide (Australia)**
Environmental	Water Quality Water Quantity	Water Resources and Availability	3 rivers originating from the glaciers (75% from Rimac River) Groundwater in dry seasons 17% of treated wastewater is reused[1]	Ephemeral rivers (depending on rainfall). 20% from Groundwater. 20% from reclaimed water[3]	River Murray (33%), other surface water (59%) Harvested storm water, treated wastewater Desalination (2%) and Groundwater (6%)[7]
		Water use Water Stress drivers	342 l/day/capita[1] Human and political issue[1]	200 l/day/capita[4] Droughts and increasing population[3]	227.125 l/day/capita[8] Long droughts and changing water flow patterns[9]
		Drinking and ambient water	41% of water disinfected in rural areas Discharge of wastewater into water bodies intrusion of saltwater into groundwater[2]	No illness related to the drinking of reclaimed water Vulnerability of groundwater due to artificial recharge[5]	Low incidents of diseases or illness. partially *e. Coli* in harvested storm water Discharge of polluted stormwater[10]
		Wastewater Treatment	15% of the collected wastewater is treated. Untreated wastewater is discharged or used for crop irrigation[1]	Wastewater is treated into drinking water and non-potable water to be used in irrigation[6]	Treated wastewater is used for irrigation or discharged into water bodies[10]

		Criteria	Lima (Peru)	Windhoek (Namibia)	Adelaide (Australia)
Socio-cultural	Awareness Health Pop.	Density Growth Rate	237/ km² [1] 1.5% per year [1]	79/ km²[18] 5% per year[19]	404/km² [23] 2.3% per year [24]
		Illiteracy	Country's rate: 6% [12]	Country's rate: 24%[20]	Country's rate: 1%[25]
		Poverty Rate	23% of the population of Peru [13]	29% of the population of Namibia[13]	8% of the population of South Australia[13]
		Life Expectancy Child Mortality	83[13] 14/1,000 live births[14]	64[21] 69/1,000 live births[22]	75 [26] 4 /1000 live births [26]
		Extent of Awareness	Measures to reduce water pollution are common among the public	Acceptance of drinking treated wastewater and environmental awareness[6]	Public are aware of water desalination process [27]
		Perception	Water problems are not perceived as a major challenge[15]	Low public concern about future water supplies and unawareness of water supply process[6]	Acceptance of drinking recycled water[27]
		Allocation of Water Services	Supply Access: 70%[16] Sanitation Access: 69%[16]	Supply Access: 99.8%[6] Sanitation Access: 83%[6]	Supply Access: 99.6%[28] Sanitation Access: 80.9%[28]
		Allocation of Water Between Sectors	Highest share for domestic sector; followed by agriculture, then green space, industries, and mining [17]	Highest share for agriculture sector; followed by livestock, then domestic and industry[30]	Highest share for agriculture sector; followed by domestic, then industries and mining[29]

		Criteria	Lima (Peru)	Windhoek (Namibia)	Adelaide (Australia)
Economic	Water Fees Financial Viability	Affordability	Areas with no water connections spend 10 times more, leading to less water consumption[31]	Higher water costs (relative to income) in informal settlements leads to less water consumption by 50%[35]	Almost third of low-income customers have difficulty in paying their water bill. Water supply restrictions in case of non-payment[37]
		Willingness to pay	The majority of the population are not willing to pay more, even for improved water quality[32]	Citizens believe that water should not be paid for or should be always offered at low prices[36]	Higher educated residents promote higher water costs to promote water conservation[37]
		Cost of Water Per Household	High income residents < 0.8% of income[33] Low-income residents 4.1% of income[33]	High income residents < 4.5% of income[35] Low-income residents 29% of income[35]	High income residents 0.4% of income[37] Low-income residents 1.8% of income[37]
		Cost of Water for Businesses	Significantly higher than the domestic one	Slightly higher than the average water uses for domestic users	Almost equal to the highest tariff for residential users
		Subsidy	60% of consumers do not benefit from the subsidy[34]	Subsidization for commercial irrigation farmers, even for inefficient water use[36]	Rate remission for water fees for low-income residents[38]
Governance	Stakeholders	Key Actors	The national government is fully responsible for policy making related to water and sanitation. Communal organizations provide water services, supervised by local and regional authorities[39]	The government is fully responsible for the management of water resources. A separate organization provides water in rural areas[41]	The government is fully responsible for the management in urban and rural areas Irrigation trusts manage irrigation in rural areas[11]

	Criteria	Lima (Peru)	Windhoek (Namibia)	Adelaide (Australia)
Policies Knowledge Participation	Extent of Contact Between Authorities and the Public	The Health and Environmental Education Program promotes water awareness and public engagement Dissemination of knowledge to the public on the water day of Peru[32]	Educational programs increase the awareness and the acceptance of drinking reclaimed water in addition to customer advice, public participation and distribution of efficient water use pamphlets[4]	Customers' satisfaction is evaluated and users are engaged in the planning process. Community reference group are set up to exchange ideas[27]
	Decentralization	Private provision is present in a small percentage of urban areas due to public opposition[34]	Rural water management is decentralized, where technical decisions are taken in the regional branches instead of headquarters[41]	Private firms have been assigned operation and maintenance of infrastructure by long-term contracts or the irrigation in rural areas[42]
	Availability of Knowledge	A website for the dissemination of knowledge by SWITCH[40]	Lack of information readily available to its citizens[4]	Digital information platform is used to provide knowledge to public[27]

	Criteria	Lima (Peru)	Windhoek (Namibia)	Adelaide (Australia)
	Policies	Housing Resolution: prioritize and allocate investment in the sanitation sector. The Water Resources Act: regulates for the discharge and reuse of treated wastewater The Solid Waste Act: governs the solid waste produced during wastewater treatment[1,40]	Water Resource Management Act, 2004: aims at equity and transparency of water access. Windhoek Managed Aquifer Recharge Scheme: concerned with recharging treated water into an aquifer[19]	Water Resources Act principal legislation governs the management, allocation and use of water resources and embodies the principles of sustainability The National Water Initiative (NWI) Statewide policy for water sensitive urban design [8]
	National Plans	The National Sanitation Sector Plan: quantifies the amount of investment required for universal sanitation coverage. Green Infrastructure regulatory framework Green Infrastructure Master Plan[1,40]	Integrated water demand management policy, 1994 Integrated Water Resource Management Plan for Namibia, 2010 Integrated Urban Water Management Master Plan for City of Windhoek[19]	The Murray-Darling Basin Plan in 2012: Impacts of Climate Change on Water Resources[8]

Current state and water management approaches in the studied cities

3.1.1. Lima is tackling water injustice through communal organizations

The coastal city Lima (Peru, Fig. 3A) faces insufficient water infrastructure, overexploitation and contamination of groundwater, poor disinfection of water in rural areas, discharge of wastewater into surface water and lack of sewage systems leading to the use of septic tanks, causing ecological problems. Lima also lacks an efficient rainwater collection and reuse system, and only a small percentage of treated wastewater is reused (Carroll, 2017; Gammie and De Bievre, 2014; Carreazo et al., 2006).

The population lack sufficient information about water status and challenges in Lima, water is only perceived as an economic value. To raise awareness and engage citizens, the Ministry of Housing, Construction and Sanitation (MVCS) in Peru celebrates the water day every year with competitions, field visits and capacity building programs (Simon, 2018). Residents of informal areas consume much less water than those in high income areas. They also pay higher prices for it and spend the highest proportion of their income on water. 60% of consumers do not benefit from the water subsidy (Felgendreher and Lehmann, 2012).

In Lima, there is a centralized governance system, and the population is opposed to privatization. The MVCS in Peru oversees the sanitation sector (Furlong, 2016). The Superintendencia Nacional de Servicios y Saneamiento (SUNASS) is the governmental regulatory entity for the water service providers. The Servicio de Agua Potable y Alcantarillado de Lima (SEDAPAL) is the water provider in Lima (Vilcara and Karina, 2009). Communal organizations (JASS) are officially assigned by the MVCS to provide water services to 85% of the population in rural and peri-urban communities in Peru. Households that are members of these associations are simultaneously owners of the water infrastructures and users of the service. They participate in construction and maintenance and, in turn, get access to the water services for a small monthly fee (Calzada et al., 2017).

SEDAPAL has launched a multibillion-dollar Master Plan (2015–2040) to address water and sanitation needs in Lima, focused on adaptation of the water infrastructure for future demand increases and reduction in water availability. It has also started investing in aquifer recharge projects to prevent and manage overexploitation and ensure meeting future demands and is undertaking measures to increase the wastewater collection level to reduce water contamination. SEDAPAL is also developing a Master Plan for green infrastructure in response to droughts and heavy rains. This aims to preserve the ecosystem and prevent erosion (Carroll, 2017). The "Mechanisms of Compensation for Ecosystem Services" law was passed to enforce using part of the water tariffs in green infrastructure projects, climate resilience and risk management.

3.1.2. Windhoek uses treated water for potable and non-potable purposes

Windhoek in Namibia relies on ephemeral rivers, groundwater, and treated wastewater (Fig. 3B). The city faces water scarcity due to the increase in population and urbanization, lack of water infrastructure investments, poor capacity building, high water pollution and extreme droughts (Scott et al., 2018). In addition, artificial recharge of groundwater has led to an increase in the aquifer's vulnerability to contaminants.

The city of Windhoek is the first in the world to use treated water for potable and non-potable purposes (Boucher et al; 2011). Windhoek has carried out educational programs to increase the awareness of water consumption and the acceptance of drinking reclaimed water, and has also promoted customer advice, public participation and distribution of efficient water use information (Rensburg, 2006). Citizens accept and derive pride from the fact that they are the only city in the world where reclaimed water is used for drinking (Lahnsteiner and Lempert, 2007). However, the majority are not aware of the treatment process of water treatment and supply, leading to high water consumption rates. Due to desalination's negative impacts on the environment, the public is generally against it (Kgabi and Mashauri, 2014).

A block tariff system is used in Windhoek to enable water conservation and subsidization. In informal settlements, a flat rate is used, where water fees are charged for the whole community. This system is unfair due to non-payment by some individuals, leading to higher payment by others. In addition, people in informal settlements pay higher percentages of their income compared to those in high income areas (Kastner et al., 2005). The public perception of the value of water is generally low (Flod and Landquist, 2010).

The government has full responsibility of water resources in the country. Within the Ministry of Agriculture, Water, and Forestry (MAWF), the Department for Water Affairs is responsible for the water management, regulation of bulk water supply and provision of water in rural areas (Liehr et al., 2018). The Department of Infrastructure, Water and Technical Services (CoW) oversees the supply, distribution, and quality of drinking water in urban areas. The Namibia Water Corporation (NamWater) is the national supplier of bulk water. The structural organization for water management in Namibia lacks coordination.

In Windhoek, water demand management has shown promising results since it was initiated in 1994 (Lahnsteiner and Lempert, 2007). An Integrated Urban Water Management Master Plan for the City of Windhoek was launched to provide the city with a strategy for sustainable development and operation of water and wastewater infrastructure for the next 20 years (African Water Facility, 2017). A Water Demand Management Strategy and the Drought Response Plan were set up to address water shortage and use during droughts. The Windhoek's Save Water campaign aims to reduce residential water consumption by 40%. The National Water Saving Campaign aims to ensure that water wastage is curbed in all governmental institutions. Finally, the Windhoek Managed Aquifer Recharge Scheme aims to increase the long-term sustainability of the water supply capacity by recharging treated water into an aquifer during intense rainfall, for use in times of drought (Scott et al., 2018).

3.1.3. Adelaide uses a digital platform to disseminate knowledge

The main water resource of Adelaide in South Australia is the surface water in the Mount Lofty Ranges, the River Murray and groundwater (Fig. 3C). Treated wastewater is used for non-potable purposes. Efforts are made to provide water through desalination in drought periods (Government of South Australia, 2014). Harvested rainwater was found to contain high levels of *E. coli*, making it unsuitable for recreational use (Chubaka et al., 2018). The city suffers from prolonged droughts, resulting in the production of sulphuric acid and the release of heavy metals and other contaminants, posing health risks and negative impacts on the environment and water supplies. In addition, water resources are polluted due to use of pesticides (Government of South Australia, 2003).

South Australia Water (SAWater) is a business enterprise that is owned by the government and is responsible for the provision of water services in South Australia. SAWater launches educational programs, site tours, expos, presentations, as well as market and social research to engage the customers and raise their awareness. It relies on digital information to provide knowledge to its customers through a user-friendly website with an interactive map of the water network and resources. SAWater uses phone and online surveys to measure the customer satisfaction, in addition to focus groups and one-on-one interviews. The organization engages its customers, communities and stakeholders in the planning and delivery of capital and business development projects (EPA, 2016).

Low-income households pay a higher percentage of their income compared to higher income households. About third of low-income customers have difficulty in paying their water bill (South Australia Council of Social Services, 2017). The government offers rate remission to those who cannot afford payment, in the form of protection from restriction of water services, offering flexible payment plans and alleviation of legal actions (SA Water, n.d.1).

The Department for Water in the Government of South Australia is the main manager of water resources in South Australia. SAWater is the only water service provider. Some private firms have been assigned the operation and maintenance of infrastructure by long-term contracts (Keremane et al., 2017). SAWater contacts its customers frequently to measure their satisfaction with the services provided and find out about their perception and opinions of its performance, using surveys and phone calls, as well as focus groups and one-on-one interviews (SAWater, n.d.2). The company also engages stakeholders in the planning and delivery of capital and business development projects through community information sessions and community reference groups (EPA, 2016).

Water for Good, a plan set up in 2009 to ensure water security of South Australia up to 2050, outlines actions to promote diversity of water resources, improve the allocation and use of water and improve its industry. By implementing the stated actions, Greater Adelaide will only need water restrictions once every 100 years, aside from conservation measures (Government of South Australia, 2010). A statewide policy for water sensitive urban design includes targets addressing the water quality. The Murray-Darling Basin Plan in 2012 provides for the integrated management of the Basin's water resources. In addition, it ensures a sustainable future supply of drinking water for Adelaide and other regional communities, keeping the Murray Mouth open, flushing salt from the system, and providing flows to precious River Murray wetlands and floodplains and supporting a sustainable irrigation sector (Government of South Australia, 2014).

3.1.4. Cairo has witnessed water educational and awareness campaigns and events

The arid city of Cairo is dependent on the Nile River (Fig. 3D). It represents about 95% of the total country's water resources. Cairo faces a rapid increase of its population, raising the demand of freshwater resources. Water stress is also caused by inefficient pipe network and water pollution due to industrial activities (Gad, 2017). Irrigated lands in Egypt suffer urban encroachment and deterioration due to salinity of irrigation water. Salinization is a result of inappropriate water management at field level and lack of drainage system, reuse of drainage water by large quantities, which is loaded with salt (FAO, 2016). Egypt is one of the pioneer countries in the reuse of water. All drainage water of Upper Egypt returns to the River Nile raising its salinity. Drainage water is mixed with fresh water and reused for different purposes (Abdin and Gaafar, 2009).

Water has been perceived as a public good which is supplied at a nominal price in Egypt (Khedr, 2007). The Ministry of Water Resources and Irrigation (MWRI) has carried out media campaigns to spread awareness. It also carried out workshops and distributed knowledge and facts about water status (GreenCOM, 2006). The Cairo Water Week started is organized annually by the MWRI to promote awareness and innovative solutions for water challenges. Access to water services in Egypt is uneven and depends on geographical and socio-economic conditions (World Bank, 2015). The official water tariff is unaffordable for those in extreme poverty (about three million people). They tend to illegally connect to water services, risking fines (Hutton, 2012). Current water tariffs are insufficient to cover the operational expenses.

The Ministry of Housing, Utilities and Urban Communities (MHUUC) is the main institution involved in the urban water and sanitation. The MWRI is responsible for development, distribution, maintenance, policy making, efficiency, quantity, and quality of water resources, in addition to all specifications and permits for water resources uses. The Ministry of Agriculture and Land Reclamation (MALR) is in charge of agricultural research and extension, land reclamation and agriculture (FAO, 2016). Egypt has a rich experience with the water users' associations (WUAs) in the field of agriculture. They allow farmers' participation in management, operation, and maintenance of water systems. However, WUAs have no legal status, which among other things constrained their ability to collect money and act as independent bodies with full private ownership (Rap et al., 2015). The Egyptian Water Regulatory Agency (EWRA) is responsible for publishing and dissemination of information, reports, and recommendations.

This provides users with information about their responsibilities and rights and raises their awareness. (Mumssen and Triche, 2017).

The National Water Resources Plan for Egypt 2017–2037 (NWRP – 2037) is funded by the EU and aims at organizing, at the national and governorate level, the optimal water resource allocation. It involves coordination of key staff in the MWRI to monitor the implementation of action plans. The National Rural Sanitation Programme 2015 aims at providing universal access to sanitation in rural Egypt, through financing investment in the areas deprived of sanitation infrastructure (World Bank, 2018). The Joint Integrated Sector Approach (JISA): is a donor co-ordination mechanism aiming at enhancing investment effectiveness in the irrigation sector by means of an improved coordination of investment planning and implementation within the MWRI of the Government of Egypt (European Commission, 2018).

3.2. Stakeholders' analysis and comparison

The organizations and stakeholders in each of the case studies and in Egypt were studied. Organizational charts were concluded. We can see a centralized approach to water management is shared in all countries (Fig. 4). In all the studied areas, ministries hold the full responsibility of water management, while rural water services may be handled to communal organizations (such as in Peru), or to different department or authority.

An onion chart of stakeholders in the water sector in the three case studies and in Egypt was made (Fig. 5). Stakeholders were arranged according to their influence in the transition process towards water sensitive urban design. In Egypt, the Ministry of Water Resources and Irrigation and the Ministry of Water and Wastewater Utilities have the most influence in the transition and decision-making process. Following are the Ministry of Environmental Affairs, the Egyptian Water and Wastewater Regulatory Agency, Cairo Alexandria Potable Water Organization, the Holding Company for Water and Wastewater and the Ministry of Health and Population, respectively. This chart is used to select representatives from Egyptian water management organizations according to their importance in the transition.

4. Discussion

By studying the environmental, social, and economic aspects in the three case studies, as well as the physical infrastructure and governance background, we draw conclusions about key efforts in water management. Six main aspects can be identified as promising Steps towards Water Sensitive Urban Design (WSUD): i) developing integrated water management frameworks, ii) conservation of water resources, iii) educational campaigns and awareness raising, iv) public participation, v) knowledge availability and dissemination and vi) water fees subsidy (Table 4).

Table 4: Water management efforts carried out in the three case studies, Lima, Windhoek, and Adelaide, classified into six categories. A full black circle indicates that key efforts have been made towards a certain aspect, an empty circle indicates no key efforts were found in that aspect, and a half-filled circle indicates that moderate efforts were made in that aspect.

	Integrated Water Management Frameworks	Conservation of Water Resources	Educational Campaigns and Awareness Raising	Public Participation	Knowledge Availability and Dissemination	Water Fees Subsidy
Lima	●	◓	◓	●	○	○
Windhoek	●	●	●	○	○	○
Adelaide	●	●	◓	◓	●	●
Egypt	◓	○	◓	◓	○	◓

4.1. Key water management efforts in the studied cities

An integrated water management (IUWM)framework is crucial to ensure transition towards WSUD (Gabe et al., 2009). Windhoek was the first to implement an integrated water demand management policy in 1994. Adelaide was second, through launching its Water for Good plan and the Water sensitive urban design policy. Lima has also launched a master plan for water resources management and is developing a master plan for green infrastructure.

Water conservation is the basis for a future proof water management. Windhoek leads in this field. It has launched water saving campaigns to decrease the average water consumption, and the Managed Aquifer Recharge Scheme. In Adelaide, the Natural Resources Management Act 2004 regulates water use in the Adelaide region, providing water quality plans and sustainable allocation of water to the environment and consumptive uses. In Lima, the Mechanisms of Compensation for Ecosystem Services enforces a percentage of the water tariffs being invested in green infrastructure projects, enabling management, and saving of water resources.

Educational campaigns and awareness raising are crucial for a paradigm shift in urban water use needs to reach the user. Windhoek also leads in the educational aspect, as it has carried out intensive campaigns to raise the public awareness. These have successfully changed the citizens’ perception towards accepting drinking of treated wastewater. In Adelaide, educational campaigns have also been launched to educate the public about water resources and issues. In Lima, the Health and Environmental Education Program in 1993 aimed to spread water conservation and rational use.

Public participation promotes responsibility along the rural-urban continuum (Mukhtarov et al., 2018). Adelaide’s water fees subsidy allows for equity. Given the scarcity issues of water resources, providing water services at convenient fees is critical. Very low prices promote irrational and wasteful use of water and lead to lack of funding for governmental water projects. While offering water at economically preferable costs, where water is perceived as a product, leaves large amounts of low-income citizens with no access to their rightful share of water resources. Many subsidy systems for water services offer water at free or minimum prices, while still failing to serve the poor. At many cases, rural areas are not connected to water supply systems, thus, they pay higher prices than city residents who benefit from the subsidized services. Subsidy systems should consider provision of water services for the lowest income group at affordable prices (Europäische Kommission, 2000). The government of South Australia has been providing rate remission for citizens unable to pay the water fees, creating a sense of trust and equity between the customer and the government. Urban and rural areas receive water supply and sanitation access. Incapable citizens are offered flexible payment plans, alleviating legal actions and protection from water supply restrictions. No key efforts were found in Lima and Windhoek for both aspects.

The availability of a user-friendly website including information about water services provides customers with an easy access to sufficient knowledge. The Government of South Australia supports and encourages the dissemination and exchange of public sector information. SA helps citizens, businesses, entrepreneurs, and industry discover openly licensed data so that it can be transformed into ideas, applications and visualizations which benefit the community. WaterConnect is a website that contains the state's key water information. It provides access to information about water resources and activities in South Australia, including data about the current water permits, approvals, licenses and allocations, reports about groundwater status and aquatic ecosystems and publications the state of certain water resources and impacts of climate change (Environment Protection Authority South Australia, 2013).

4.2. Adaptation of policies and actions to Egypt

Based on the studied cities and their water management approaches, we draw conclusions about which elements can be adapted and used in Egypt to provide a set of policies and actions to enable transition towards WSUD. We propose four approaches that can address the main water challenges in Egypt. These approaches address water conservation, public participation and water subsidy, availability and dissemination of knowledge and awareness raising. The approaches are:

Water fees Supporting the Ecosystem

This approach supports utilities to collect fees for water use and allocate them to different projects for projects that increase the water quality and at the same time the quality of life for people in the community, by implementing sanitation and water supply networks. Collected fees are also used in land conservation projects, land and water use, and design and use of hydrologic monitoring systems. We suggest that the Holding Company for Water & Wastewater in Egypt become the responsible organization for implementing the policy to ensure development of water services and implementation of ecosystem projects.

Water Service by and to the Public

This approach supports communal organization by giving them the required authorities to be officially in charge of water services provision in these regions. This will allow provision of water services to rural areas at low costs, with the participation of the residents in the operation and maintenance of the water systems. Egypt has already a large experience with Water User Associations (WUAs) in the agricultural sector. However, WUAs lack legal status, which leads to constraining their ability to levy money and own the infrastructure. We recommend the Ministry of Housing, Utilities & Urban Communities legally assign water services provision in rural areas to communal organizations, while ensuring the provision of sufficient funds, supervision, and instructions.

Interactive Water Data Base

This approach includes a digital portal provided by the government to support and encourage the dissemination and exchange of public sector information. Availability of data will promote development of the water sector, trust, and responsibility among citizens. We recommend the Egyptian Water Regulatory Agency, due to its role in disseminating knowledge, to be responsible for this online platform between the government and the people.

Wastewater Treatment to Drinking Quality

This approach aims to create a new water resource to meet the population demands, along with building the acceptance of the public to drink treated wastewater. We recommend that the Ministry of Water Resources and Irrigation take initiative for creating policies and guideline and establishing projects for the treatment of wastewater into drinking water.

4.3. Stakeholder's Interviews

After interviews and discussions with representatives from different organization in Egypt, we collected their feedback about the four proposed actions and policies.

Discussions indicated that application of the *water fees supporting the ecosystem policy* is not currently convenient to be applied in Egypt. But it would be applicable when the economic conditions of people increase, so water subsidy can be alleviated, and then the collected water fees would cover the actual service fees. Only then, a portion of the fees can be used for environmental projects. Concerning *water service by and to the public*, representatives stated that that communal organizations were experimented in Egypt in specific areas. But most efforts didn't continue. The challenge will be the poor awareness of individuals and the lack of training. When asked about *treatment of wastewater to drinking water*, they indicated that treated wastewater is normally used for agriculture, which takes up to more than 80% of the water resources. Thus, treatment of wastewater for drinking would be more costly and insignificant, as existing freshwater resources are sufficient for drinking purposes. Focus should be directed to treat all wastewater to be used in irrigation. Almost all representatives supported the *water knowledge base* and stated that this would be a successful strategy. The moderator of the website should be the holding company and the ministry of water resources and irrigation. A valuable opinion was to create a general organization for water management in Egypt, which can be also in charge of the website, to ensure it has all data from different organizations.

5. Suggested Actions For Transition Of Egypt Towards A Water Sensitive Design Approach

After examining the feedback of the representatives, in addition to the study of the cities, we included the final suggestions to the water management organization charts in Egypt, in addition to proposed actions. Some of the suggestions from the representatives were very valuable and thus, listed in the final recommendations. These are categorized into two levels:

At the organizational level, the main recommendation is to establish a General Organization for Water Management. This should directly be below the Cabinet of Ministries. The organization should consist of members from different representative of ministries and organizations in the water sector. The main role of this organization is hold councils frequently to decide on strategies and actions for water management. It is responsible for decision making in the water sector. All ministries and organizations in the water sector are obliged to follow its decisions and strategy. That ensures an integrated approach, were decisions are based on a single strategy, leading to a sustainable and successful implementation. The suggested chart is as in Fig. 6.

Secondly, we recommend creating a strategy to improve the economic conditions of the low-income category, to allow alleviation of water subsidy. This will ensure water is used in a rational way that cuts off wastage. In addition, it will provide more funds for the Holding Company of Water and Wastewater to focus on projects that improve water access and services. When collected fees is sufficient, it may also be used for green infrastructure projects and conservation of the ecosystem, which will, in turn, preserve water resources.

Next, we recommend enforcing fines for water wastage and focusing on raising the public awareness about water challenges and the economic value of water, to ensure rational use and conservation of water resources, which means less amounts of water is wasted. In addition, educating the public will allow creation of communal organizations that participate in water management, acceptance of alternative water management methods and using treated wastewater in recreational areas. Schools should be provided with educational sessions about water in an interactive way, along with workshops and competitions to engage the kids.

Finally, we highly recommend establishing the Water Knowledge Base. An interactive website that is available for the public and all stakeholders should include an interactive database about water resources conditions, challenges, and threats. It should provide a platform for communication between citizens and authorities. This should be moderated by the previously suggested 'General Organization for Water Management' as it includes representatives from all ministries. This variety is needed to provide an integrated knowledge base about water in Egypt. This will provide awareness and education to the public and raise water conservation efforts.

At the community level, we recommend ensuring new communities are in line with the country's strategic water management plan that will be prepared through 'The General Organization for Water Management'. Regulations should include using a cluster design for new communities to allow decentralized water collection and filtering techniques and to lower the required piping; separation of grey water from houses, other buildings and specially mosques; collection of rainwater in times of heavy rain; use of the collected rainwater and greywater for landscape irrigation; spray irrigation and using fresh water for car and street cleaning should be strictly banned; using natural decentralized water filtering and storage techniques such as ponds, swales and constructed wetlands to filter rainwater and greywater and act as reservoirs for storage till reuse; using areas for natural water management as recreational areas for the public too, with sufficient safety measures; using specific landscape plants that require less water and promoting water efficient fixtures in houses and other buildings by offering discounts on the water bill.

In addition, we recommend the use of urban design as an educational tool. The design of the community should consider the water cycle in the beginning of the planning process. Water professional should collaborate with urban designers and planners to design a community that uses water efficiently. This includes providing spaces for alternative water treatment methods. The integration of water solutions through the design will work on raising the public awareness of the water cycle and the value of water. When the citizens recognize its economic value and are educated about the treatment process and the efforts to provide them with clean water, they will be more aware of their patterns of use. Involving natural water treatment and storage methods in public spaces will also act as educational tools for the public, especially children. Thus, communities can act as an awareness and educational tool.

6. Conclusion

The lessons drawn from the study show that efforts towards a water sensitive approach can be successful in Egypt. Willingness of the government to transform water management practices is essential for change. The government should address all dimensions (environmental, socio-cultural, economic, and physical infrastructure). Successful transition of water management requires integration of environmental, socio-cultural, economic, and governance dimensions. The studied cases show that a top-bottom approach is required. Coordination and collaboration between ministries and organizations in the water sector is critical to successful integrated water management. Ensuring that water pricing allows for development of services, while considering subsidies for the low-income groups is important to promote more projects that preserve environmental resources. Awareness raising is important for successful continuity of communal organization and participation. Providing knowledge about water data and issues is the foundation for trust in governmental institutions. Finally, establishing communities according to the national water management plans promotes the inclusion of urban designers and planning in water management.

Declarations

Conflict of Interest

The Authors declare no Competing Financial or Non-Financial Interests.

Author Contributions

ZE: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing-original draft, Writing-review & editing

AA: Contact for the interviewees, Supervision

IS: Conceptualization, Supervision, Validation, Writing-review & editing

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article.

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Figures

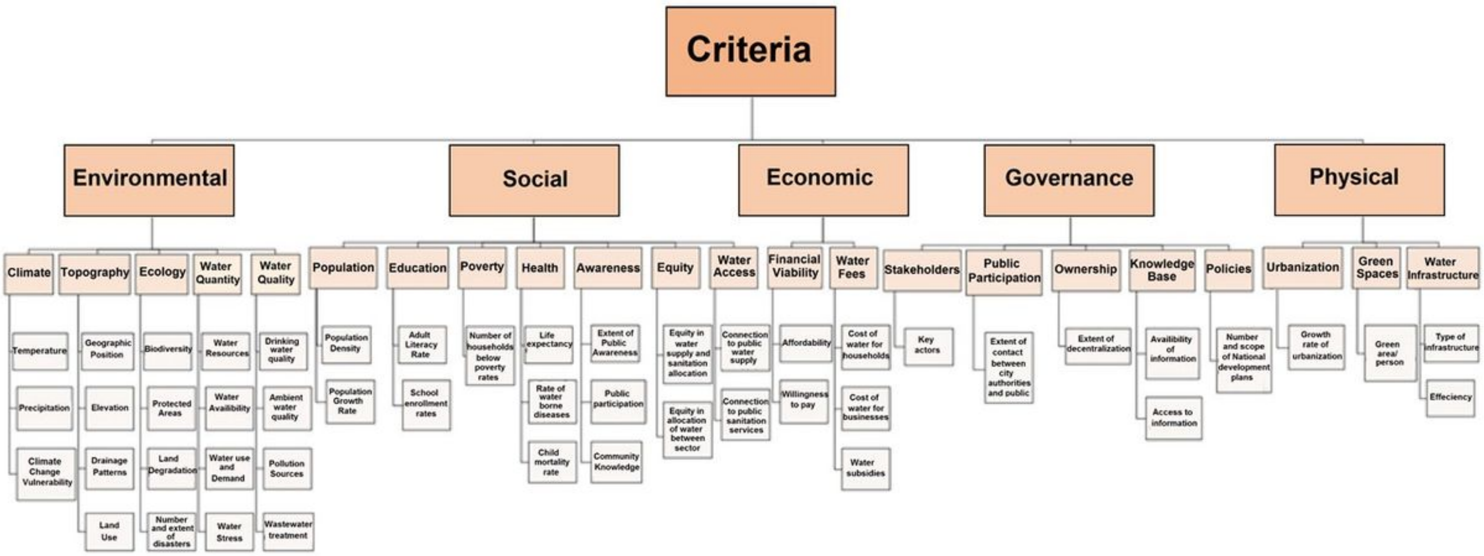

Figure 1

Criteria to assess Water Sensitive Urban Design approaches in Lima (Peru), Adelaide (Australia) and Windhook (Namibia) based on literature review of 129 review papers on keywords ‘sustainable urban water management' OR 'water sensitive cities'.

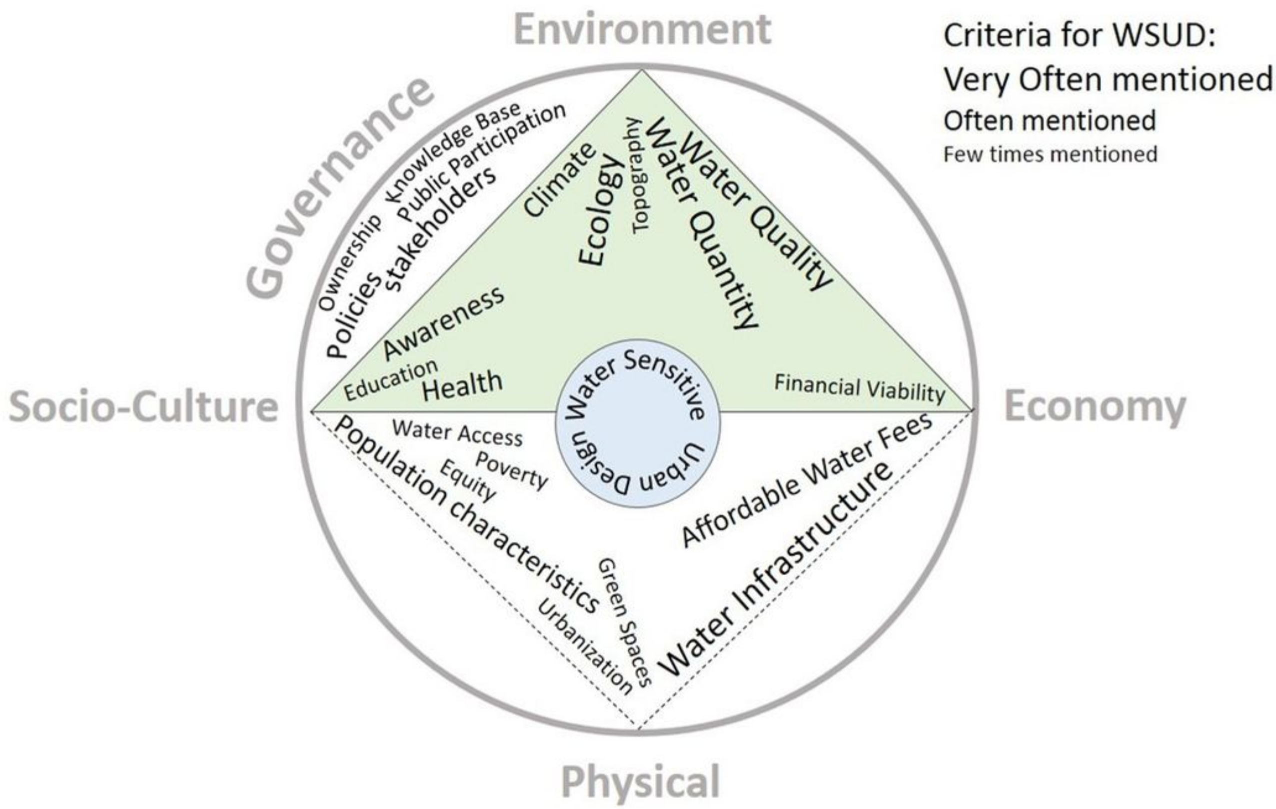

Figure 2

The selected set of criteria classified into five dimensions (Environmental, Social, Physical, Economy and Governance). The figure shows their relation to water sensitive urban design. The governance dimension acts as the integrative actor between the other dimensions. A set of criteria is selected for each dimension. The importance of each is shown by its font size.

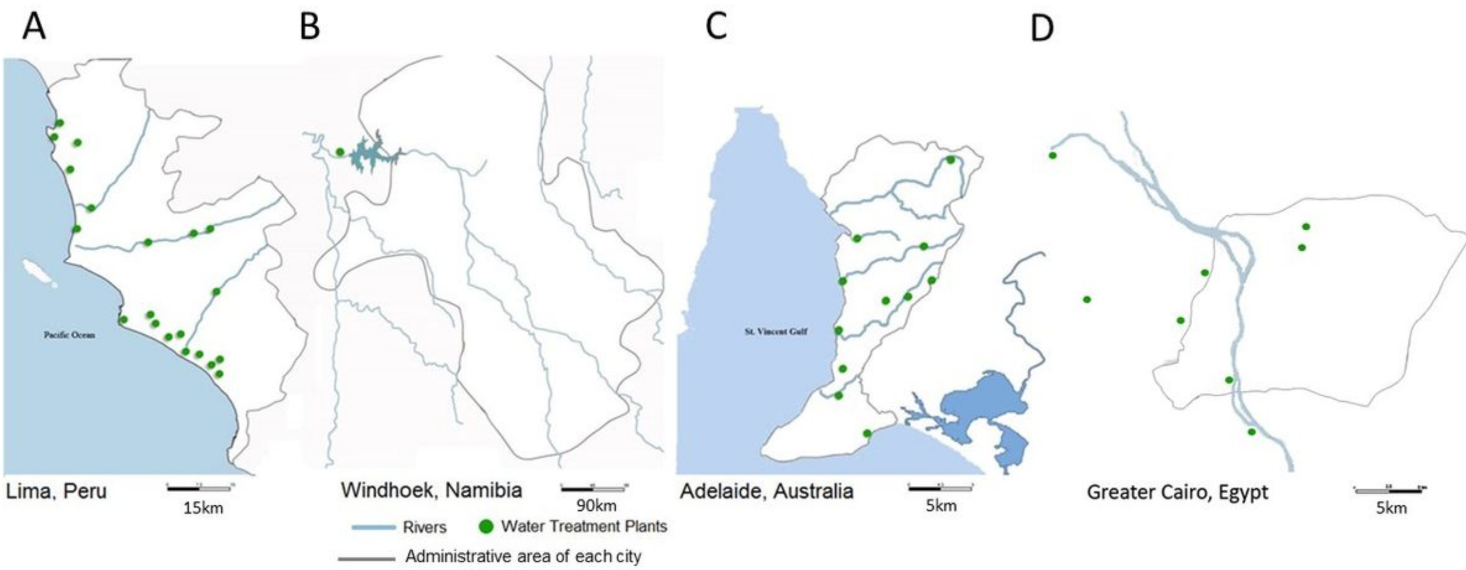

Figure 3

Maps of the three selected cities and Cairo showing the administrative borders of each city, rivers, and water treatment plants in each.

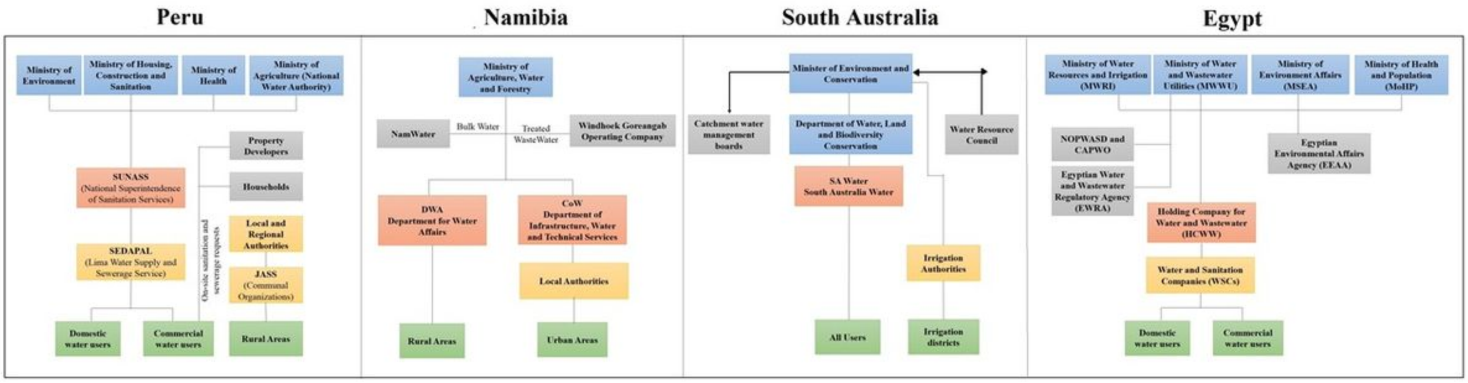

Figure 4

Comparison of the water service providers in the three case studies and Egypt. The key actors include governmental, regional, and local actors, in addition to standalone organizations and end-users.

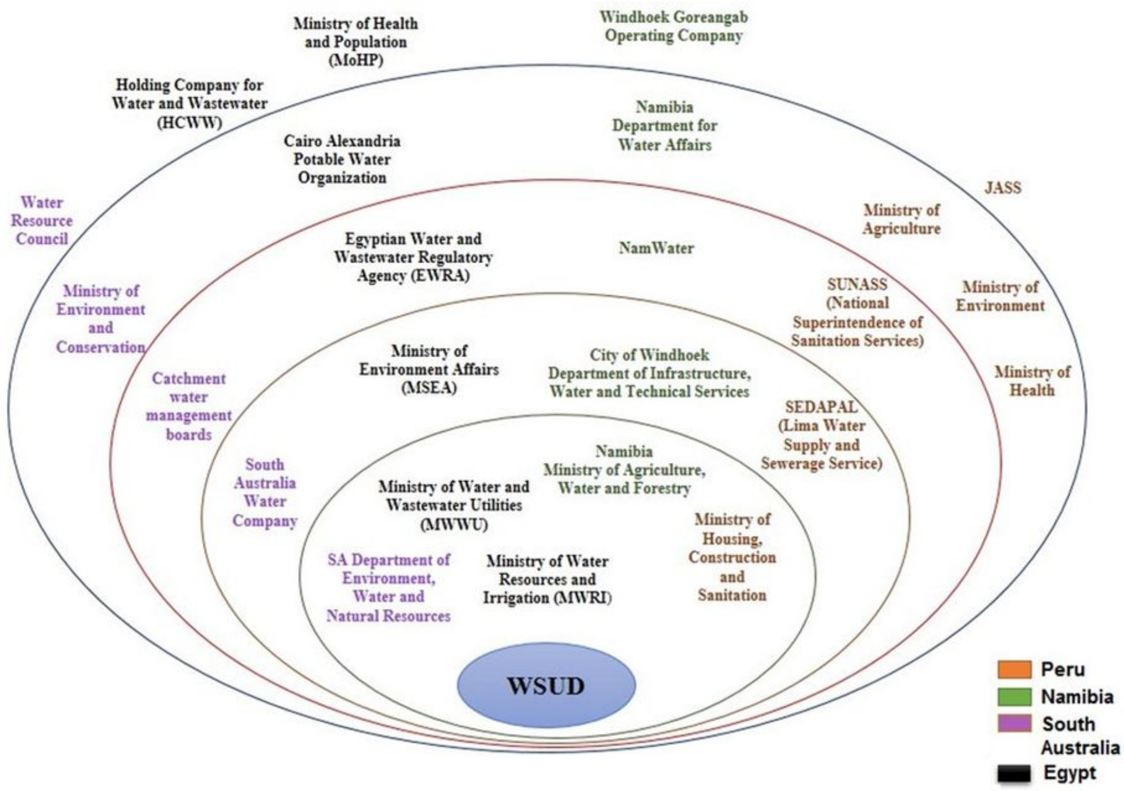

Figure 5

Onion chart of stakeholders in the water sector in the three case studies and in Egypt. Stakeholders are arranged according to their influence in the transition process towards water sensitive urban design.

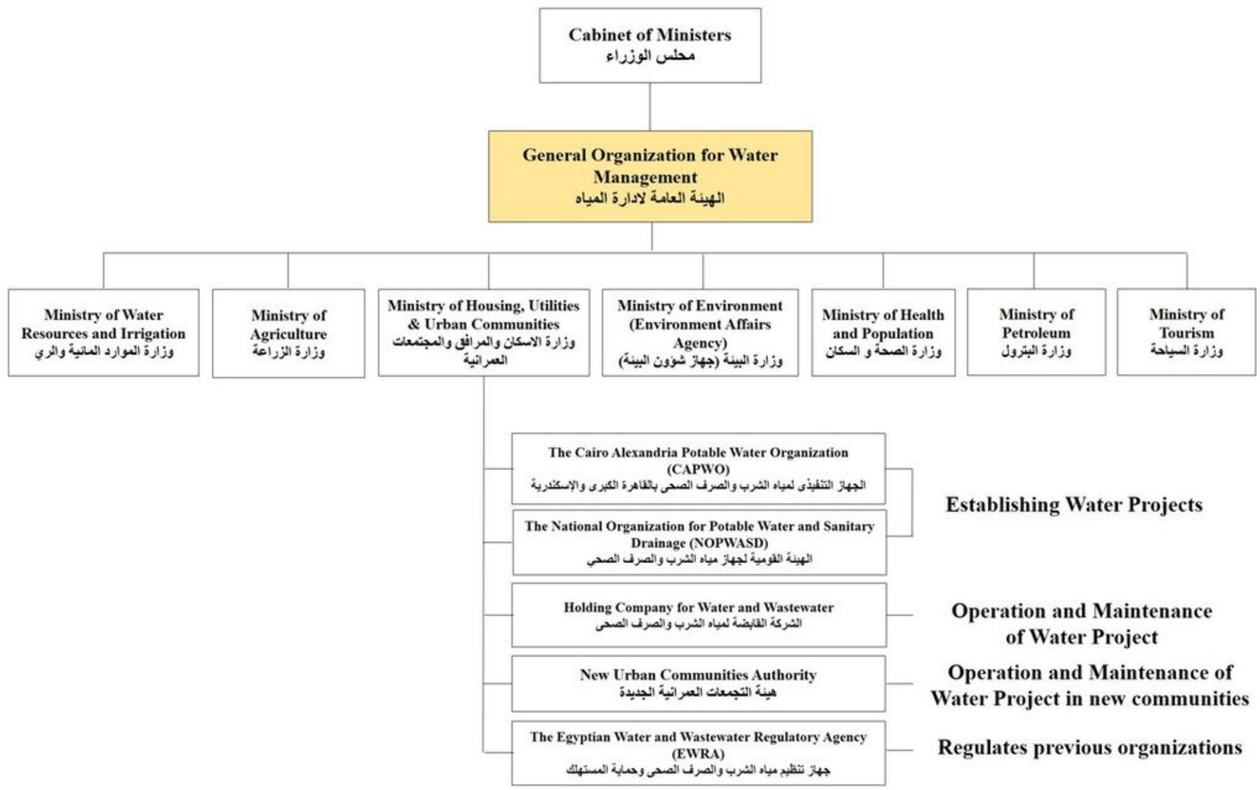

Figure 6

Final suggested organization chart for key stakeholders in the water sector after the feedback from the interviews (A general organization for water management was added to ensure cooperation between all stakeholders)