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EDITED BY
Leon M. Hermans,
IHE Delft Institute for Water Education, Netherlands

REVIEWED BY
Ali Moridi,
Shahid Beheshti University, Iran
Ömer Ekmekcioğlu,
Istanbul Technical University, Turkey

*CORRESPONDENCE
Ina Säumel
ina.saeumel@hu-berlin.de

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Lessons learned from water-scarce cities: Proposed policies toward an integrated urban water management in Egypt

Zeina ElZein[1,2], Amal Abdou[1] and Ina Säumel[2]*

[1]Architecture Department, Faculty of Fine Arts, Helwan University, Helwan, Egypt, [2]Integrative Research Institute THESys Transformation of Human-Environment-Systems Humboldt-Universität zu Berlin, Berlin, Germany

Water scarcity is one of the main challenges facing countries in arid or semi-arid zones. As an example, Egypt needs to deal with both insufficient quantity and quality of water for residents. Here, we propose actions and policies to promote an integrated water management approach to respond to water challenges in Egypt. Based on a literature review, we have selected a set of criteria concerning the environmental, economic, social, governmental, and physical dimensions of urban water management. We studied approaches from Peru, Namibia, and South Australia as these countries have similar climatic conditions and water issues and have made substantial advances toward sustainable water management. Key criteria are state or municipal ownership of water and related infrastructure, agreement on master plans for sustainable water management, improvement of water sanitation and overall infrastructure, and reduction of water demand. Participatory, and educational campaigns put water issues at the center of public debates. We evaluated which elements of water management approaches can be adapted and used in Egypt, which faces limited freshwater resources, and which faces a highly increasing population. Proposed actions included directing water fees to ecosystem projects, treatment of wastewater to be potable, participatory approaches that engage the community in water management, educational campaigns that lead to change of public perception and knowledge dissemination. We interviewed key stakeholders in the water sector in Egypt to validate our proposed approaches. The stakeholders supported knowledge dissemination, suggested using water fees in implementing environmental projects and criticized converting wastewater into drinking water. Finally, we drafted specific recommendations at the organizational and urban levels of water management. We recommended establishing a General Organization for Water Management to oversee water-related organizations and ministries. We also recommended prioritizing the economic conditions to support alleviation of water subsidy, increasing public awareness, and creating a public database for water knowledge. In addition, we recommended decentralized water

management and water sensitive urban design. The value of these approaches is their applicability, with minor adaptations, to countries with similar or close climatic and socio-economic conditions to Egypt, such as the MENA region.

KEYWORDS

water sensitive cities, sustainable water management, transition framework, drought cities, arid and semi-arid cities

Introduction

The world water crisis is not about too little water to satisfy human needs, but about poor 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). 1.8 billion people will be living in areas facing absolute water scarcity by 2025. 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). Water scarcity is directly linked to health (Moe and Rheingans, 2006; DeNicola et al., 2015; Livingston, 2021; Paudel et al., 2021). During the COVID-19 pandemic, for example, it was particularly difficult for those living in areas with poor access to water to comply with hygienic measures (UNESCO, 2021; Boretti, 2022). In addition, closing borders, restricting movement, and increasing poverty will enhance food and water shortage, which might be much more worrying than the spread of the virus (Boretti, 2022).

Today's assessment of water scarcity still does not reflect its multi-layered nature and focuses mainly on population, availability and use of water (Liu et al., 2017). Often missing are a holistic analysis of environmental flows to conserve functioning of aquatic ecosystems; an adequate inclusion of water quality indicators such as concentrations of pollutants, green and virtual water flows at the global level; and the temporal variations of all water system components (Liu et al., 2017; Hussain et al., 2022). A transdisciplinary approach including environmental, socio-economic and governance dimension of water scarcity is crucial to develop sustainable mitigation strategies (Jerneck et al., 2011; Damkjaer and Taylor, 2017).

Egypt, an arid developing country; with 95% of its population concentrated in the urban agglomerations of the Nile Delta and Valley (El-Ramady et al., 2019), has already exceeded the water scarcity threshold (1,000 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 the local lakes such as Manzala and Mariout (African Economic Outlook, 2016). In addition, the redistribution of people to new cities will pose more pressure on local water resources. These underscores the need for new water management approaches (Nikiel and Eltahir, 2021).

Concepts of Integrated Urban Water Management (IUMW) or the so-called Water Sensitive City are shifting the urban water paradigm to a holistic management of the water cycle (Mitchell, 2006; Fletcher et al., 2007; Brown and Farrelly, 2009; Fletcher, 2010; Nieuwenhuis et al., 2021). Moreover, IUMW includes all stakeholders in planning and decision making, values all existing forms of water as potential resources, considers anthropogenic and ecological requirements, includes all perspectives of sustainability and balances different needs across different time scales (Mitchell, 2006). Specific guidelines for efficient water management assure that the evaluation of any development project is also based on their impact on water resources (Karamouz et al., 2010; El Bedawy, 2014) and minimize the negative impacts of urbanization within the catchment area. Whereas current water management methods contradict goals of sustainable development, IUWM supports the idea that convenient systems reflect local environmental, social, cultural, and economic conditions, instead of a single idea that fits all (Mitchell, 2006). Thus, IUWM specifically focuses on cities that are expected to rapidly expand, and thus, their water concerns will grow larger in the coming years (Costa et al., 2015). Moreover, not only deals with the physical aspect of water management, but also involves the interdependency of stakeholders and objectives to increase the efficiency of the urban economic structure (Karamouz et al., 2010).

Water management research in Egypt is often carried out by single-discipline researchers, discouraging the involvement of civil society (Barthel and Monqid, 2011). However, our transdisciplinary study adopts integrated approach by involving knowledge on environmental, social, economic, governmental, and urban/physical aspects of water management and practical expertise by local stakeholders. As global challenges such as water scarcity cannot be addressed by a single perspective, the value of this approach is to include different experiences and backgrounds to ensure that the final proposed policies and actions are integrated approaches that consider all the dimensions. We use multi-objective simulation and

optimization models have been successfully employed in basins of the Near East region (Avarideh et al., 2017; KhazaiPoul et al., 2019; Hatamkhani et al., 2021; Hatamkhani and Moridi, 2021 for Iran and Iraq). Moreover, Egypt is currently pursuing different avenues to achieve its sustainable development goals for 2030. This study provides policies and actions to move Egypt toward these goals.

We propose a set of priorities for promoting an integrated water management approach adapted to the local context and challenges. To do so, we reviewed experiences of successful water management efforts in areas with climatic and water conditions similar or close to Egyptian cities (Lima, Peru; Windhoek, Namibia and Adeleide, Australia). Selection depended on having.

We (i) present the set of criteria to analyze water management approaches in the case studies, (ii) adapt the approaches to the Egyptian context, (iii) carry out interviews with key stakeholders in the Egyptian water sector to validate the applicability of the approaches, and finally, and (iv) provide proposed actions to promote the integrated water management approach in Egypt.

Materials and methods

We used a mixed method approach with different steps in this study (Figure 1). We started with a systematic literature review to define relevant criteria that will be used as case studies (Lima, Peru, Windhoek, Namibia, and Adelaide, Australia), in addition to Cairo, Egypt. We analyzed the case studies based on the criteria. We identified possible strategies and measures and discussed them with local stakeholders in Egypt and we recommend specific policies and actions, from the case studies, that can be adapted to Egypt.

Literature review and selected criteria

A literature review was carried out to identify a set of criteria for studying water management approaches in arid cities. We conducted a qualitative review of all scientific articles written in English on criteria for urban water management decisions in the Web of Science following the PRISMA guidelines by using keywords covering "urban water management" and the different categories criteria to which management measures can be assigned. Selection of criteria was based on the three components of sustainability (economic, environmental, and social dimension). We also added the governmental dimension as the transition to sustainable urban water management requires collaborative efforts among all stakeholders and governmental power and will (UN, 2010). This dimension considers 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 advanced keyword search (November 2018) in the Web of Science revealed 1980 references related to urban RWM measures in the "topic" or "title" fields. We first screened the titles and abstracts of the remaining articles and eliminated articles that were not related to our topic. If there was any doubt, we kept the article for the next step of the review process. Then, we eliminated articles without access to the full text version and sent requests to the most relevant ones. Thirdly, we made a full text review of the remaining 126 articles to gather the relevant information. The whole process was conducted independently by two reviewers who jointly reported a synthesis in the Supplementary Appendix I.

Figure 2 shows the relation between the five dimensions, while showing the selected criteria of each dimension. The criteria for the environmental dimension include climate 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 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

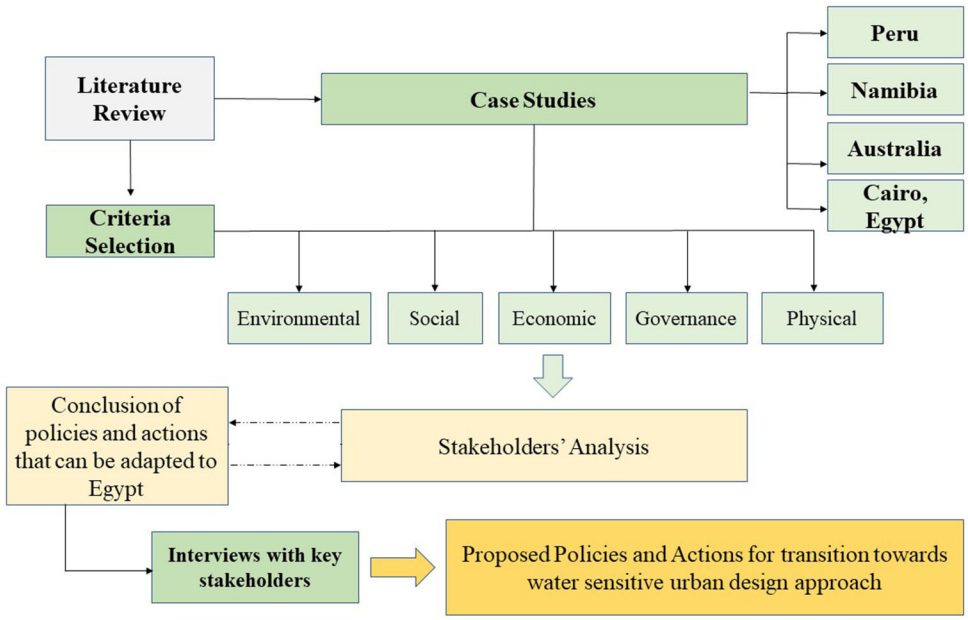

FIGURE 1
Methodology used in the study starting by the literature review, till the proposed policies and actions.

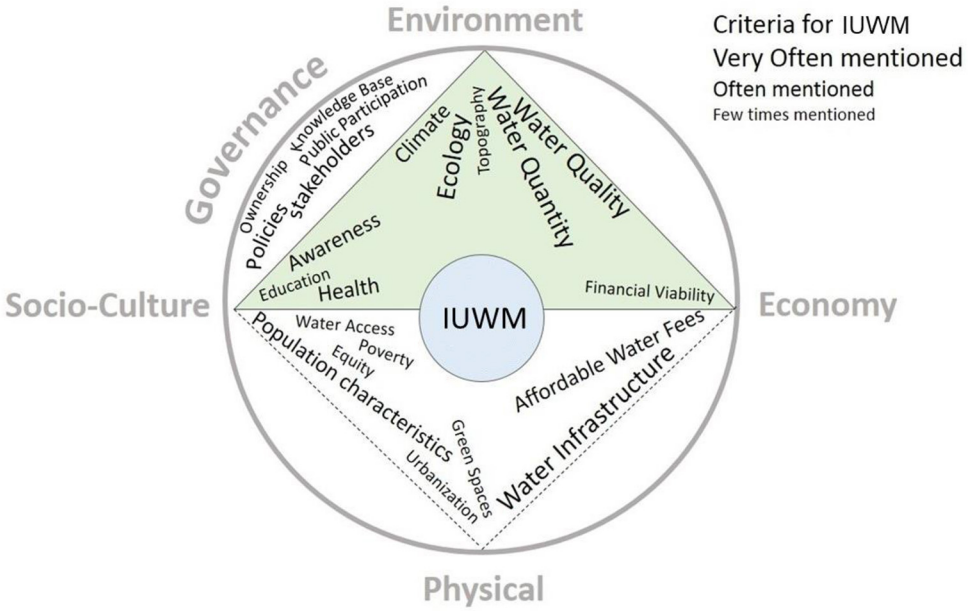

FIGURE 2
The selected set of criteria classified into five dimensions (Environmental, Social, Physical, Economy, and Governance). The figure shows their relation to integrated urban water management. The governance dimension acts as the integrative actor between the other dimensions. A set of criteria is selected for each dimension (see details in Supplementary Appendix I). The importance of each is shown by its font size. Further analysis of the case studies based on the detailed criteria is presented in Supplementary Appendix II.

the relationship between the public and private sectors; and integrated policies to determine water demand management measures, including water tariffs, pollution charges, leakage control and restrictions.

The physical dimension includes urbanization, which requires 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 which needs to be selected according to efficiency, appropriateness, cost, and potential for adaptation to the local environment and future changes (European Commission, 2000). Physical water infrastructure supports water service provision to the community to sustain itself through agriculture, industry and human consumption (Karamouz et al., 2010).

Case studies

Selected case studies (Figure 3) share challenges of water quantity and quality, along with vulnerability to climate change. They 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. Lima, Peru has a desert climate and is considered the second driest capital of the world after Cairo (Egypt). Lima has undertaken efforts of transition to a sustainable water management system and green infrastructure (Barrett, 2017; Carroll, 2017). Windhoek, Namibia is facing drought and water shortage and is the first city in the world that treat wastewater into safe drinking water and has carried out successful efforts for raising the public awareness and acceptance (Lahnsteiner and Lempert, 2007; African Water Facility, 2017; Scott et al., 2018). Adelaide, Australia has faced many droughts including the Millennium Drought (2001–2009), causing severe impacts on the water quality of the River Murray and flooding and is currently in the process of transition toward an integrated management of its water cycle (Government of South Australia, 2010, 2014). After identification of the case studies the literature review process was done again for each case study, also including accessible local literature, websites and documents regarding urban water management policies, measures and stakeholders involved.

Identifications and evaluation of learnings

We categorized the integrated water management efforts in the case studies into six aspects: (i) development of 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. We discuss here each of the six categories and highlight the efforts done by the case studies in each compared with Egyptian state of the art (Table 1) to identify promising fields of action for Egypt Stakeholder with relevant influence in the decision-making process were identified in all case studies and Cairo, Egypt following Reed (2008). Stakeholder interviews were carried out with representatives from key organizations in the water sector in Egypt. These organizations were selected based on the onion chart and their influence on decision-making and transitioning toward an urban water management approach. We used an explorative approach of qualitative, semi- structured, one-on-one interviews (Ryan et al., 2009) to provide insights from relevant stakeholders, their role, and their evaluation of the current state of the art of the urban water management in Egypt and their perspectives on potential policies and actions that can be adapted to Egypt. Each interview consisted of three questions: (1) Representatives were asked to state the problems facing water management in Egypt according to their opinion and experience. (2) They were asked to arrange the key stakeholders according to their influence in the transition process toward urban water management. (3) They were then asked to evaluate and give their feedback to the suggested policies and actions, and their applicability in Egypt. Thus, each interviewee could elaborate on their own terms, unfolding points of deeper meaning within an individual's statement. Participants' statements amplified the perspectives originated from different policy and governmental documents by individuals' contexts, experiences and interests. We adopted their feedback to our suggestions and provide final recommendations for the transition of Egypt to integrated urban water management.

Results

We present the observed status of urban water management efforts in each of the case studies, based on the comparison with the set of criteria (see Supplementary Appendix I). In each section, we highlight the key aspect of integrated water management efforts that is implemented in the case study. We also discuss an overview of the water challenges, population, and governance of the water management in each case. In Supplementary Appendix II, we provide a detailed analysis of the case studies based on the selected criteria.

Current state of water management approaches in the studied cities

We carried out an analysis of the case studies according to the selected criteria (Supplementary Appendix II). We identified different water management approaches in the case studies and highlighted the key aspects of each city in terms of the selected dimensions. The detailed criteria analysis helped us identify potential approaches for Egypt.

In the following sections, we summarized key aspects regarding the environmental, social, physical, economic and

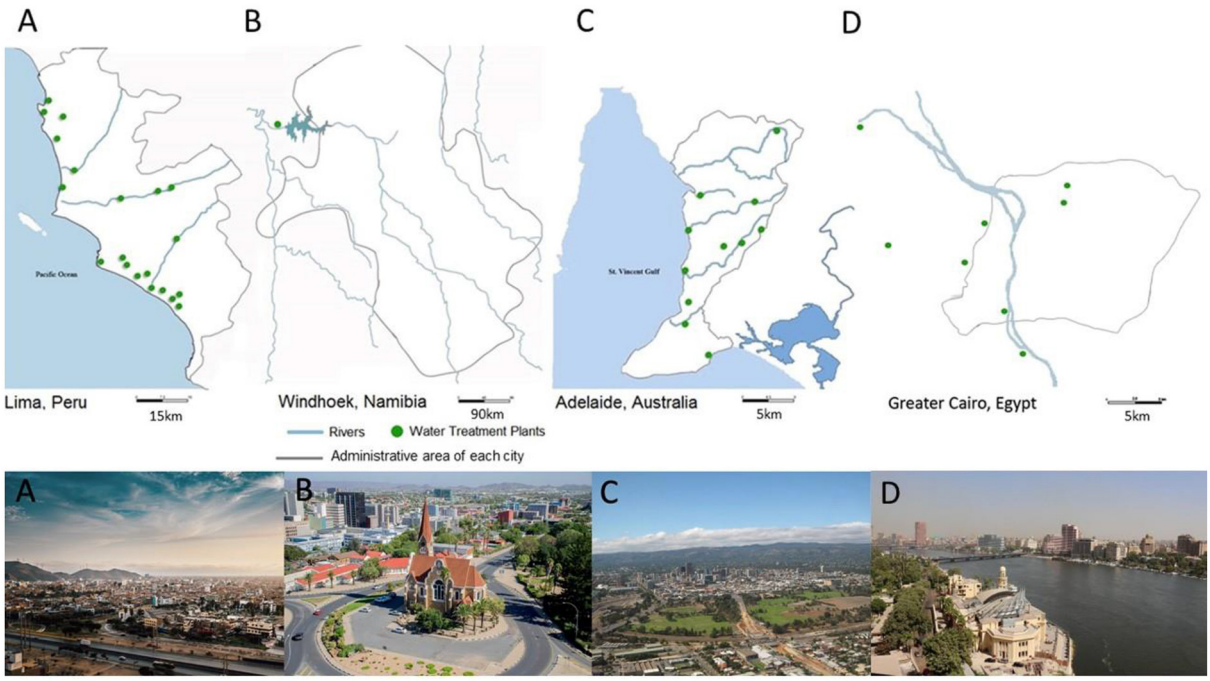

FIGURE 3
Maps and photographic impressions of Lima **(A)**, Windhoek **(B)**, Adelaide **(C),** and Cairo **(D)** showing the administrative borders of each city, rivers, and water treatment plants in each. Sources of photos: Aarom Ore **(A)** from Unsplash, Dave Beaumont **(C)** from Flickr, wboroma **(B)**, and Remon Samuel **(D)** from Pixabay.

governmental dimensions for the case studies and potential for further adaptation (see Supplementary Appendix IV).

Lima is tackling water injustice through communal organizations

The coastal city Lima is characterized by a hot desert climate. It is vulnerable to increased droughts and water scarcity due to climate change. It is situated in Peru, which is one of the top 10 biodiverse countries. The city primarily relies on three rivers originating from the glaciers, as water resources the population growth for the country is 1.5% per year, with an illiteracy rate of 6% and a 23% poverty percentage About 70% of the population is connected to water services. Peru has an urban population of 78%, and water infrastructure is characterized by weak continuity and efficiency (Sara et al., 2014; Carroll, 2017; CIA, 2018; World Atlas, 2019; ClimateData, 2019).

Lima 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 (Carreazo et al., 2006; Gammie and De Bievre, 2014; Carroll, 2017).

The population lacks sufficient information about water status and challenges in Lima, and 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 World 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 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.

Windhoek uses treated water for potable and non-potable purposes

Windhoek, Namibia is characterized by a semi-arid climate, where there is a threat of increasing temperature, droughts and water scarcity. Namibia is considered an international biodiversity hotspot. The population growth rate is 5% per year, with illiteracy rates of 24% and poverty rate of 29%. Almost all the population is connected to water supply, while about 80% is connected to sanitation services. Urban population represents 49% in Namibia, with an urban growth of 4.3% (Government of Namibia, 2015; CIA, 2018; Scott et al., 2018; World Atlas, 2019; UNdata, 2019).

The city relies on ephemeral rivers, groundwater, and treated wastewater. It 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.

Windhoek is the first city in the world to use treated water for potable and non-potable purposes (Boucher et al., 2011). It 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 (van Rensburg, 2006). Citizens accept and take pride 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 for water resources in the country. Within the Ministry of Agriculture, Water, and Forestry (MAWF), the Department for Water Affairs is responsible for 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. There is a lack of coordination between organizations responsible for water management in Namibia.

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's intent is 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).

Adelaide uses a digital platform to disseminate knowledge

Adelaide is characterized by a Mediterranean climate. It faces risks of decrease of rainfall, drying of aquatic ecosystem and changes in the water regime to ephemeral. Population growth is 2.3% per year, with an illiteracy rate of only 1% and poverty rate of about 8% of the whole population of South Australia. Urban population represents 86% in Australia, with growth rate of 1.7% (Harding, 2012; Jaeckel, 2014; Cox et al., 2016; SAFCA, 2018; SA Planning Portal, 2018; Worldatlas, 2018; Population Australia, 2019).

The main water resource of Adelaide is the surface water in the Mount Lofty Ranges, the River Murray and groundwater. 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 by an updated, user-friendly website. The website provides improved fault information and an interactive map showing when and where water mains are being replaced, as well as details on pipes within the existing network. All these digital solutions were developed in consultation with customers throughout the design, build and trial phases which was critical to the success of the program. In addition, 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 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). Low-income households pay a higher percentage of their income for water 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 in the form of protection from the restriction of water services to those who cannot afford payment. It also, offers flexible payment plans and alleviation of legal actions (SAWater, 2019a).

The Department for Water in the Government of South Australia is the 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 frequently uses surveys and phone calls, focus groups and one-on-one interviews to measure customer satisfaction with their services provided and find out about their perception and opinions of its performance (SAWater, 2019b). 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 established in 2009 to ensure water security of South Australia through 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).

Cairo has witnessed water educational and awareness campaigns and events

Cairo is characterized by a hot desert climate. Egypt faces the risks of decreasing rainfall and sea level rise, leading to flooding and low food production affecting economy. Population growth rate is around 2% per year, with illiteracy rate of 28% and poverty rate of 32%. Urban population represents 43% in Egypt, with urban growth of 2% (El-Sayed Hassan, 2013; World Bank, 2015; Zaki and Swelam, 2017; CAPMAS, 2019; World Atlas, 2019; World Population Review, 2020).

Cairo is dependent on the Nile River (Figure 3D), which represents about 95% of the total country's water resources. Cairo faces a rapid increase in 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. In addition, irrigation water is provided free of charge (Gharib, 2004).

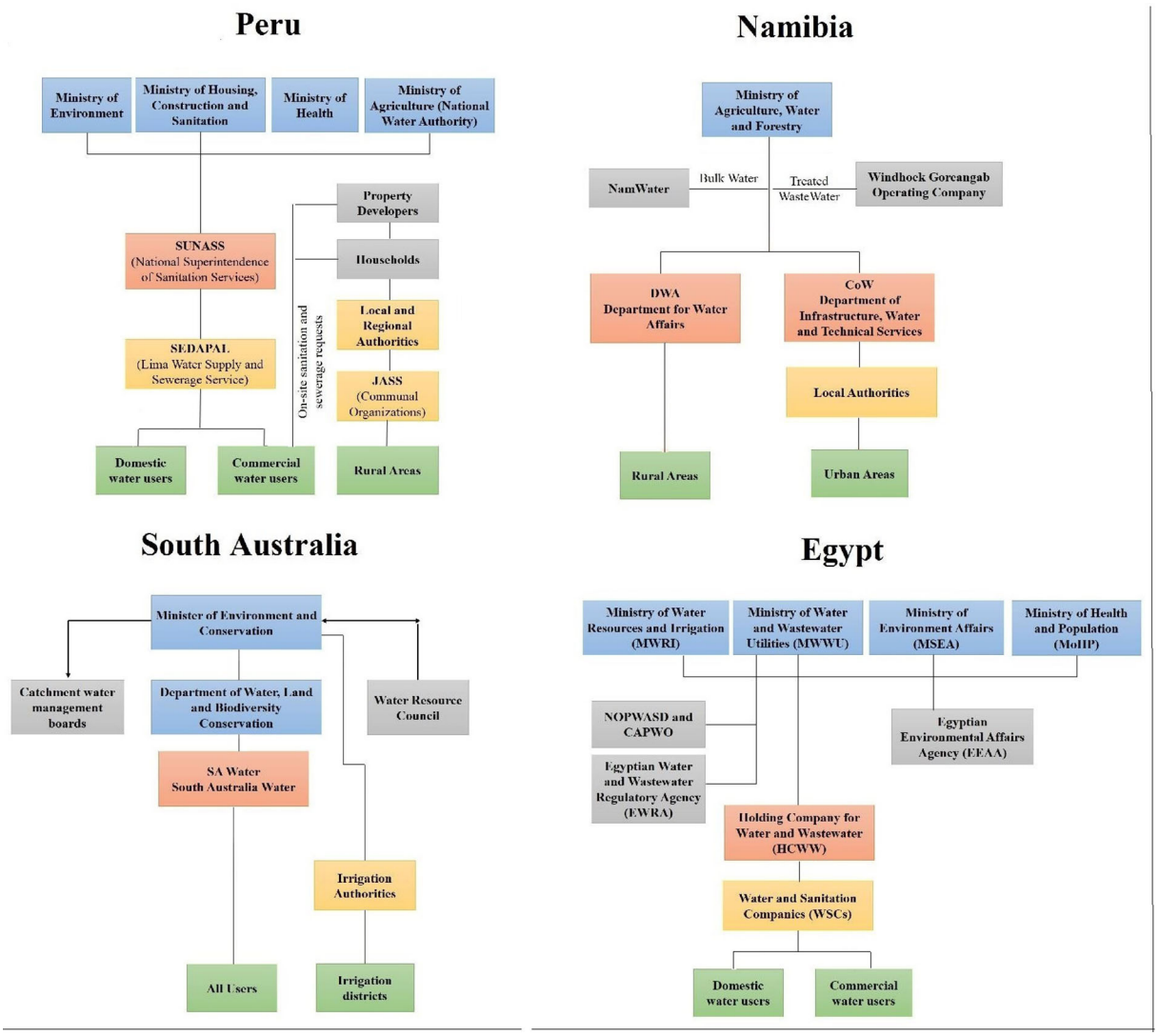

FIGURE 4
Comparison of the water service providers in the three case studies and Egypt. The key actors include governmental, regional, and local actors, in addition to standalone organizations and end-users. A hierarchical approach in water management in all studied cases, with some differences in rural and urban water management. In the figure, organizations that are perceived at the same administrative and influence level for water management are assigned with similar colors (based on Australian Government, 2003; Harding, 2012; Ioris, 2012; Furlong, 2016; Mumssen and Triche, 2017; Nghipangwa, 2017; Scott et al., 2018).

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 user 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. WUAs in Egypt have also shown low participation levels, poor comprehension of possibilities and actions, lack of the sense of partnership between the associations and MWRI. In addition, there is a need for clear instructions from higher governmental levels (Rap et al., 2015).

The Egyptian Water Regulatory Agency (EWRA) is responsible for publishing and disseminating information,

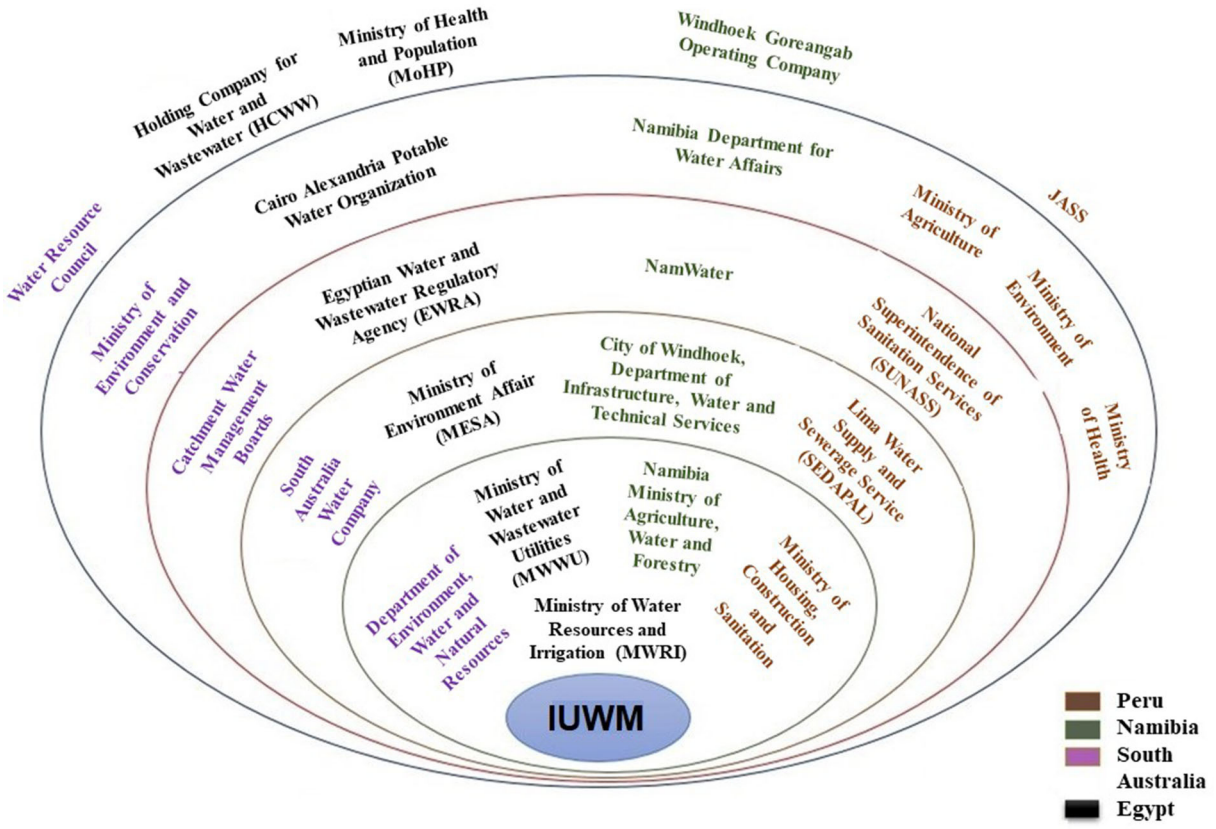

FIGURE 5
Onion chart of stakeholders in the water sector in the three case studies and in Egypt. Stakeholders are arranged according to their influence in the transition process toward water sensitive urban design. The goal to develop an integrated urban water management approach is at the center, from there the stakeholder are arranged in layers from high influence on decisions (inner layer) to lower influence of actors in the environment (outer layer). IUWM, integrated urban water management; JASS, Juntas Administradoras de Servicios de Saneamiento in Peru. The chart is based on the literature review and on the stakeholders' interviews. Background information can be found in Supplementary Appendix II and for details see result section and Supplementary Appendix III.

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 safeguarding water resources with consideration of the socio-economic conditions. It involves coordination of key staff in the MWRI to monitor the implementation of action plans. The National Rural Sanitation Programme 2015's goal is 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 intending to enhance 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).

Stakeholders' analysis and comparison

The organizations and stakeholders in each of the case studies and in Egypt were studied based on the literature review (for details see Supplementary Appendix III). Organizational charts (Figure 4) were concluded based on the Australian Government (2003) and Harding (2012) for South Australia; Ioris (2012) and Furlong (2016) for Peru, Mumssen and Triche (2017) for Egypt; and Nghipangwa (2017) and Scott et al. (2018) for Namibia. A centralized approach to water management is shared in all countries. In all the studied areas, ministries hold the full responsibility for urban water management, while rural water services may be handed to communal organizations (such as in Peru), or to different departments or authorities. The aim is to understand the responsibilities of each ministry or organization to be able to assign the suggested actions to the convenient stakeholder, discussed later in the study.

However, the influence of the stakeholders' is also strongly shaped by the individual agendas of organizations due to their sectoral functioning. Thus in a second step, stakeholders were arranged according to their influence in the decision-making regarding integrated urban water management based on literature. We created an onion chart of stakeholders (Walker et al., 2008; Singh, 2009) in the water sector in the three case studies (Figure 5).

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 those 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. To validate this arrangement, we asked the representatives from key institutions in the water sector in Egypt during the interviews to arrange the stakeholder's influence according to their own perspectives. This provided deeper insights and feedback based on their real-life experience. Stakeholders were arranged according to their influence in the decision-making toward integrated urban water (Walker et al., 2008; Singh, 2009). We created an onion chart of stakeholders in the water sector in Egypt based on the literature reviews and on the interviews (Figure 5). This chart is used to identify the responsible stakeholders for the suggested policies and actions.

Discussion

A large body of literature highlights the importance of the nexus between water, energy and food for urban sustainability (Zhang et al., 2019). However, in recent decades calls for better coordination of urban resource management, such as between land and water management (Mitchell, 2006) or within water management concepts focusing on different water types such as storm- or wastewater (Nieuwenhuis et al., 2021), have largely gone unheard. A lack of coordination between different sectors such as water and land is a very common phenomenon in cities worldwide, even though most water and land processes are interdependent (Stoker et al., 2022). Water management follows different integrative approaches facing additional uncertainty arising at the interfaces of subsystems (Nieuwenhuis et al., 2021). Rarely do cities have a holistic approach and pioneers such as our case studies are understandably found in arid and semi-arid areas where water issues are more pressing.

Several studies have discussed the importance of stakeholders' participation in water management. The collaboration between different concerned parties is critical to the management process. Methods for reducing conflicts between the interests of the involved stakeholders is important to develop integrated water management approaches. The proper engagement of stakeholders increases the efficiency of water management, in addition to creating a shared knowledge and a holistic approach to water management. Engagement of stakeholder links research and decision-making and provides expertise and knowledge of water resources. The success of stakeholders' involvement requires a deep knowledge of the context and environment (Dillon et al., 2016; Furber et al., 2016; Megdal et al., 2017; Shammout and Shatanawi, 2019).

Key water management efforts in the studied cases

Table 1 summarizes the water management efforts carried out in the three case studies.

Regarding integrated urban water management (IUWM) frameworks, Windhoek was the first to implement an integrated water demand management policy in 1994. South Australia launched its Water for Good plan and the Water sensitive urban design policy in 2010. Peru has also launched a master plan for water resources management in 2015 and is developing a master plan for green infrastructure. Egypt has launched an integrated plan for water management in 2017.

Namibia leads the field of water conservation. It has launched water saving campaigns, such as the Managed Aquifer Recharge Scheme, to decrease the average water consumption. In South Australia, 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 Peru, 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. Other successful water saving and retrofitting approaches in greenfield but also in urban redevelopment situations have been reported (Mitchell, 2006; Bertone et al., 2017; Campisano et al., 2017). Egypt has high water conservation techniques in agriculture (Gad, 2017), but not in domestic and industrial systems.

Namibia also leads in the educational campaigns and awareness raising aspect, as it has carried out intensive campaigns to raise the public awareness. These have successfully changed the citizens' perception toward accepting drinking of treated wastewater. In South Australia, educational campaigns have also been launched to educate the public about water resources and issues. In Peru, the Health and Environmental Education Program in 1993 aimed to spread water conservation and rational use. Two-way communication with all stakeholders and especially civic society organizations catalyze water saving literacy in a broader society outside expert circles to develop shared understanding and acting (e.g., King et al., 2019; Cotler et al., 2022).

TABLE 1 Water management efforts carried out in the three case studies, classified into six categories.

	Integrated water management frameworks	Conservation of water resources	Educational campaigns and awareness raising	Public participation	Knowledge availability and dissemination	Water fees subsidy
Peru	●	◒	◒	●	○	○
Namibia	●	●	●	○	○	○
South Australia	●	●	◒	◒	●	●
Egypt	◒	◒	◒	◒	◒	◒

A full black circle indicates that key efforts of water management have been found in the literature in a specific category, an empty circle indicates no key efforts were found in that aspect, and a half-filled circle indicates that little efforts were found in that aspect.

Concerning public participation, South Australia'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. In many cases, rural areas are not connected to water supply systems; 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 (European Commission, 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.

In the knowledge availability and dissemination aspect, 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 (Environment Protection Authority South Australia, 2013).

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 toward IUWM (Supplementary Appendix IV for selection of the approaches). We propose four approaches that can address the main water challenges in Egypt; water conservation, public participation and water subsidy, availability and dissemination of knowledge and awareness raising. Here, we suggest the actions and illustrate their outcome, along with our suggestion of the responsible Egyptian institution or organization. The approaches are:

Water fees Supporting the Ecosystem: This approach proposes a regulation or policy to enforce utilities to collect fees for domestic and industrial water use and allocate them to different national projects that improve the water supply and quality in communities and cities. Examples include implementing or development of water treatment plants and networks, natural water management solutions and sustainable drainage systems. Collected fees are also used in land conservation projects, land and water use, and design and use of hydrologic monitoring systems. Based on stakeholder analysis in the case studies and in Egypt, 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 proposes a policy to support communal organization by giving them the required authority to be officially in charge of water services provision in these regions. This will allow supply of water services to rural areas at low costs, with the participation of the residents in the operation and maintenance of the water systems. This approach will also provide support to the existing water user associations in Egypt that was mentioned previously, in addition to promoting the formation of new non-farmer associations. We recommend the Ministry of Water Resources and Irrigation legally assign water services provision in rural areas to communal organizations, while ensuring the provision of sufficient funds, supervision, and instructions.

Interactive Public 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. This portal should include data about the status of water resources in Egypt, consumption data for households, water conservation techniques and other data that concerns the public. 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. The approach should start with awareness campaigns to spread and normalize the idea of drinking treated wastewater. After achieving public acceptance, the government should focus on wastewater treatment plants that produce drinking water quality. 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.

Stakeholder's perspectives

Interviews and local 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 subsidies 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 with 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 (see also Supplementary Appendix III for more details about stakeholders' interviews).

Suggested actions for transition of Egypt toward an integrated urban water management approach

After examining the feedback of the representatives, in addition to the study of the cities, we included 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 primary recommendation is to establish a General Organization for Water Management (Figure 6). This should directly fall below the Cabinet of Ministries. The organization should consist of members from different representative of ministries and organizations in the water sector. The role of this organization is to hold frequent council meetings to decide 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, ensuring an integrated approach, were decisions are based on a single strategy, leading to a sustainable and successful implementation.

At the community level, we recommend ensuring new communities are align 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 gray 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; strictly banning spray irrigation and using fresh water for car and street cleaning; 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 until reuse; using areas for natural water management as recreational areas for the public, 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.

We recommend creating a strategy to improve the economic conditions of the low-income category, to allow alleviation of water subsidies. This will ensure water is used in a rational way that eliminates 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 are sufficient, it may also be used for green infrastructure projects and conservation of the ecosystem, which will, in turn, preserve water resources.

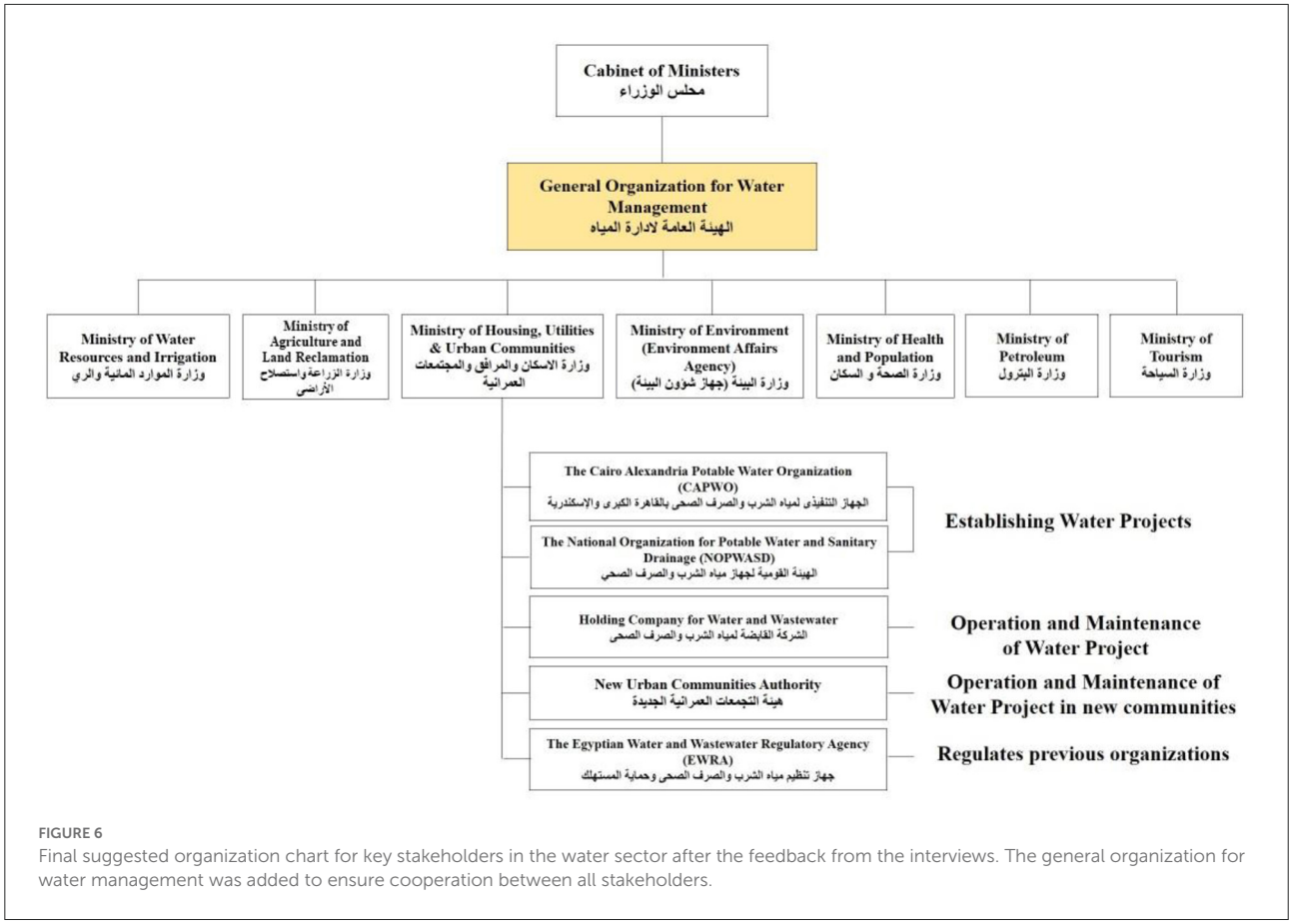

FIGURE 6
Final suggested organization chart for key stakeholders in the water sector after the feedback from the interviews. The general organization for water management was added to ensure cooperation between all stakeholders.

Next, we recommend enforcing fines for water wastage and focusing on raising the public awareness about water challenges and the economic value of water. This would 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 use of 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 beginning of the planning process, the design should consider the water cycle and water professionals 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.

The finding that institutional and economic changes are the foundation of transforming to integrated water management was found to be in line with other research findings. El Bedawy (2014) studied the current status of water resources in Egypt and the required policies and strategies to face the future water challenges. She concluded that the main issues are not due to the raised demand of water resources, but rather, the management of water, including a lack of funding, fragmentation of water management and poor public awareness

about water challenges. She clearly stated that the conflict of interest between stakeholders in the water sector is an issue. She recommended the inclusion of all stakeholders in the planning and management of water resources. In addition, she recommended institutional reform for related organizations. She highlighted that successful management in Egypt is a challenge of many actors within the water sector and beyond. This supports our recommendation of creating a general organization for water management that includes stakeholders from different aspects to ensure a holistic water management approach (El Bedawy, 2014). A study about water quality management in Egypt by Abdel-Dayem in 2014 recommended a set of actions. These were the involvement of the private sector, the coordination of responsibilities amongst authorities to avoid overlaps, reformation of management tools, decentralization of the planning process in small settlements and dissemination of standards and guidelines to the public. The study showed that changes regarding the stakeholders and institutional system of water management are critical (Abdel-Dayem, 2011). Another study stated that the sustainability of future water resources in the future for Egypt relies on coordination of stakeholders at both the national and the country levels. It also promotes strict water conservation measures and promoting agriculture measures to save water resources (Luo et al., 2020).

Lessons learned for cities suffering water-scarcity also beyond Egypt

After decades of privatization, the administration and management of water as public good (the water commons) is in governmental and communal hands (e.g., McDonald and Swyngedouw, 2019), although the reasons are manyfold (González-Gómez and García-Rubio, 2018; Voorn et al., 2020). Mishandling of water resources happens on almost all administrative levels and across all sectors involved from policy to supplier and consumer. Undoubtedly water is a crosscutting issue, where silo-thinking within departmental or disciplinary realms fails and transdisciplinary created analysis should inform participatory decision-making processes. A cross-sectoral coordination of a long-term strategic planning and an integrated management is key but often not achieved in most parts of the world.

The need for holistic multi-dimensional assessment of water-scarcity and an integration of multi-stakeholder perspectives into the development is growing. Implementation and optimization of water management measures have been widely acknowledged in theory but not achieved in practice (Damkjaer and Taylor, 2017; Hussain et al., 2022). Masterplans and mitigation strategies reviewed in our case studies aim, at a minimum, to reach a holistic approach (Lahnsteiner and Lempert, 2007; EPA, 2016; Carroll, 2017). Derived interventions and measures have to be designed, implemented and monitored in a decentralized approach and according to the place and value-based individuality of the local context, which harbors a promising potential for resilience and stability (Ostrom, 2007). Instead of setting up rigid "one fits all" solutions, that might work in one location but not another, it is better to explicitly enable co-created local learning and change driven by participatory approaches (Meinzen-Dick, 2007; Pahl-Wostl, 2015). Urban water management plans have to include the linkages and dependencies across the urban-rural continuum (Poonia and Punia, 2019).

Investments in circular economy approaches and the citywide use of treated wastewater even for potable water have been successfully piloted and demonstrated by Windhoek (Lahnsteiner and Lempert, 2007). Greener desalination technologies (Ihsanullah et al., 2021), save aquifer recharge technologies or rainwater harvesting help minimize water scarcity.

The offered approaches for Egypt can be implemented in other countries as well. In countries where the majority of the population is low-income, it is critical to work on an efficient water subsidy system that supports the targeted category. It is also important to prioritize the economic improvement of people to alleviate subsidies and establish an efficient water system, where the revenues from the services can be directed to projects that will benefit the environment. Almost most countries would benefit from establishing an online database for water knowledge. Also, assigning water management to a higher organization that oversee all other ministries and stakeholders in the water sector, will support water management efforts in most countries, and prevent conflicts and overlapping of efforts. At the community level, water sensitive urban design is key in educating the public and offering an environmental system for water management.

Conclusion

The lessons drawn from the study show that efforts toward an integrated urban water management 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. The study proves that 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. In addition, awareness raising is important for successful continuity of communal organization and public 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.

We concluded from the study a set of policies and actions that can be implemented in Egypt to promote the transition toward an IUWM approach. Our primary suggestion is to establish a General Organization for Water Management that oversees all ministries and organizations in the water sector to ensure integration of effort and mitigate conflicts and overlapping of actions. Suggestions also included prioritizing the economic conditions to support alleviation of water subsidy, which will ensure proper income for the development of water management projects. In addition, we also suggest restricting wasteful water use behaviors, public awareness, educational campaigns and creating a public database for water knowledge. Other suggestions at the community level included promotion of decentralized water management through urban design, promoting water saving landscape and equipment, in addition to using natural urban water management methods which raises the awareness of the public about water management.

Given these suggestions, further research is needed on each of the suggestions. The formation of a General Organization for Water Management should be studied in more detail to study similar cases and provide an action plan for its implementation and to set an administrative policy for the organization. In addition, research that ensures raising the awareness of the population, especially the youth, is required to include a set of actions focusing on educational campaigns for water management. Also, further research on water subsidy systems in developing countries is required to develop holistic guidelines for the transformation toward an alleviated subsidy, with consideration to the socio-economic status of the population.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

ZE: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, validation, visualization, writing—original draft, and writing—review and editing. AA: contact for the interviewees and supervision. IS: conceptualization, supervision, validation, and writing—review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frwa.2022.981261/full#supplementary-material

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