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EFFECTIVENESS OF MODERN METHODS AND TECHNOLOGIES TO OPTIMIZE WATER EFFICIENCY IN THE BUILDINGS AND EGYPTIAN URBAN ENVIRONMENT

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ABSTRACT

The current average water use per capita in the European Union (EU) is 150 liters per day, and in the United Kingdom (UK) is 142 liters per day. Singapore has reduced its domestic water consumption per capita to 148 liters per day. The EU, UK, and Singapore aim to reach 80, 110, and 140 liters per day, respectively, by 2050. In comparison, Egypt's current average water use per capita is 226.3 liters per day, with around 27.9% of the total produced pure water leaking and low-quality drinking water. This research aims to analyze applied modern methods and technologies for optimizing water efficiency in buildings and urban environments globally and investigate the current situation of using these solutions to improve water efficiency in the Egyptian urban environment. This research confirmed that global methods and technologies can effectively optimize water efficiency in buildings and urban environments. Currently, most modern techniques and tools have been used (totally or partially) in some new and existing towns and neighborhoods to improve water efficiency in those urban zones. In addition, there is the Egypt Water, sanitation, and Consumer Protection Regulatory Authority Initiative (EWRA), which aims to rationalize drinking water consumption by installing smart sanitary devices in buildings. The study recommends the widespread adoption of these initiatives, tools, and technologies in all existing and new cities and urban communities in Egypt to save about 60% of the currently produced potable water and not to be restricted to be applied in some new Egyptian towns and neighborhoods.

KEYWORDS: Arid regions, Water efficiency, Water-Energy nexus, water technologies, Green architecture.

فعالية الأساليب و التقنيات الحديثة لتحسين كفاءة المياه في المباني و البيئة الحضرية المصرية

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الملخص

يبلغ متوسط استخدام المياه الحالي للفرد في الاتحاد الأوروبي 150 لترا في اليوم ، وفي المملكة المتحدة، يبلغ 142 لترا في اليوم. وخفضت سنغافورة استهلاكها المحلي من المياه للفرد إلى 148 لترا في اليوم. ويهدف الاتحاد الأوروبي والمملكة المتحدة وسنغافورة إلى الوصول إلى 80 و 110 و 140 لترا يوميا على التوالي بحلول عام 2050. وبالمقارنة، يبلغ متوسط استخدام المياه الحالي للفرد في مصر 226.3 لترا في اليوم، مع تسرب حوالي 27.9٪ من إجمالي المياه النقية المنتجة بالإضافة الي انخفاض جودة مياه الشرب. يهدف هذا البحث إلى تحليل الأساليب والتقنيات الحديثة المطبقة لتحسين كفاءة استخدام المياه في المباني والبيئات الحضرية على مستوى العالم وتقصي الوضع الحالي لاستخدام هذه الحلول لتحسين كفاءة المياه في البيئة الحضرية المصرية. أكد هذا البحث أن الأساليب والتقنيات العالمية يمكن أن تحسن بشكل فعال كفاءة استخدام المياه في المباني والبيئات الحضرية. في الوقت الحالي، تم استخدام معظم التقنيات والأدوات الحديثة (كليا أو جزئيا) في بعض المدن والاحياء الجديدة والقائمة لتحسين كفاءة استخدام المياه في تلك المناطق الحضرية. بالإضافة إلى ذلك، هناك مبادرة جهاز مياه الشرب والصرف الصحي وحماية المستهلك (EWRA)، والتي تهدف إلى ترشيد استهلاك مياه الشرب من خلال تركيب أجهزة صحية ذكية في المباني. وتوصي هذه الدراسة بتبني المبادرات والأدوات والتقنيات على نطاق واسع في جميع المدن والمجتمعات العمرانية القائمة والجديدة في مصر لتوفير حوالي 60٪ من مياه الشرب المنتجة حاليا وعدم الاقتصار على تطبيقها في بعض المدن والاحياء المصرية الجديدة.
الكلمات المفتاحية : الأقاليم القاحلة، كفاءة المياه، تقنيات المياه، العلاقة المتبادلة بين الطاقة والمياه، العمارة الخضراء

1 INTRODUCTION

1.1 Background

Water is a valuable human life and well-being resource and a crucial component of economic efficiency and business growth. Global trends forecast about 55% worldwide growth in water use by 2050 [1]. Moreover, the world might face about 40% freshwater shortage by 2030 due to the continuous increase in freshwater consumption [2] by all sectors (household, irrigation, industry), water supply infrastructure outdatedness, inefficient irrigation systems, misuse of water resources, inefficient pricing methods, consumers behavior, consumption patterns, and climate change [1],[2]. In this context, many arid countries suffer from limited water resources and inefficient utilization. These cause freshwater shortages and constitute continuous pressures to optimize water consumption efficiency and minimize waste and leakage in the water networks of buildings, irrigation systems, and industrial facilities. As an arid region, Egypt has issues and pressure on water supplies [3], and it might become at risk of water scarcity. It has one of the world's lowest per capita water availabilities [4] and has multi-aspects of water issues in its urban environment. Therefore, this study presents many innovative technologies that have been developed and can effectively optimize water efficiency in buildings and urban environments, besides developing other tools such as pricing methods, management regulations, and institutional reforms to improve water efficiency. In this context, this research presents an analytical study about the pros and cons of the globally applied methods and technologies that could improve water efficiency in buildings and the built environment, as well as analyzes the current situation of using modern tools and technologies for water efficiency in the Egyptian built environment.

1.2 Motivation

Egypt is suffering from many aspects of the water issue that could be summarized as follows:

- According to Figure 1, the citizen's share of freshwater has been continuously declining. It reached 585 m^3 per year in 2018 [5] and is expected to be 330 m^3/p/y in 2050. That is less than the global water poverty line of 1000 m^3/p/y [6].
- The continuous increase in the domestic demand for freshwater amounted to 11 billion m^3 in 2020 [6].
- Increasing per capita average of consumed pure water to 82.6 m^3 in 2021 [6]. That is equivalent to 226.3 L/p/d.

- Limited water resources: Egypt depends on the Nile River as its essential source of fresh water [7]. According to an agreement signed between Nile Basin countries in 1959, it receives a fixed share of 55.5 billion m^3 annually [7].
- Additionally, most of Egypt's regions are arid and have little scattered rainfall. The annual averages of total precipitation ranged from 0.0 to ± 33.7 mm in 2019[8]. However, the current total water resources amounted to 81.06 billion m^3/year, while the increasing water needs in Egypt amounted to 114 billion m^3/year in 2020. Egypt suffers from an expanding water deficit [4] that is fulfilled by importing agricultural and animal products equivalent to more than 30 billion m^3/year of freshwater [7].
- Figure 2 [8] shows that the agriculture sector is the highest consumer of water as it still depends on an inefficient, traditional flood irrigation system. Previous studies revealed that the flood irrigation system in Egypt is a wasteful irrigation technique [9]. It is highly inefficient, losing as much as 3 billion m^3 of Nile water annually through evaporation, intensifying the water crisis and water stress [9].
- Leaking an enormous quantity of water supply. For example, in 2022, the percentage of water loss was 27.9% [5]. These water losses are commercial losses (meter readings and calculations, stealth links, loss of internal connections) and natural losses (leakage of pipes).
- Low-quality drinking water led people to install additional water filters in their homes to purify it.

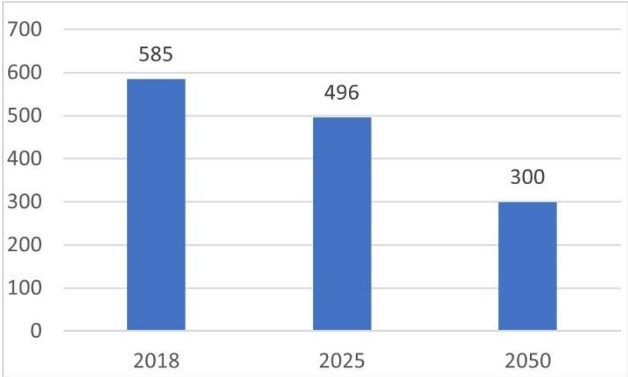

Fig. 1: Continuous decline of the citizen's share of freshwater [5]

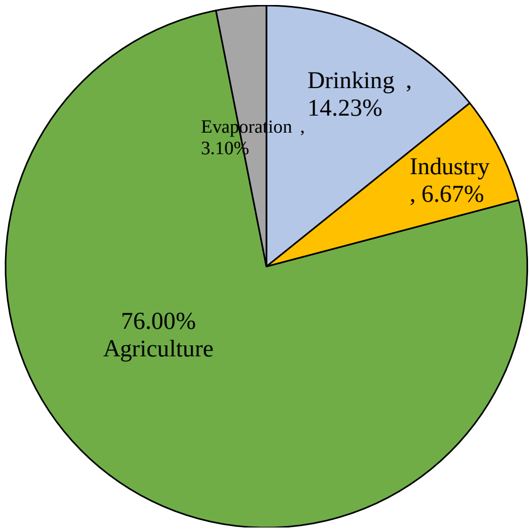

Fig. 2 Water demands per sector in Egypt 2020[8].

1.3 Literature Review

Many previous studies confirmed that modern technologies and management instruments could achieve water efficiency in buildings and urban environments. For example, previous research by Koop et al. revealed that domestic water savings could be increased through water pricing, technical improvements, policy instruments, and regulation [10]. Globally, many countries have successfully reduced domestic water consumption per capita. For example, Singapore partially successfully reduced domestic water consumption per capita to 148 L/p/d in 2016. It aims to reach 140 L/p/d by 2030[11], which has partly been achieved through program series such as water-efficient homes/buildings and awareness-raising through water conservation talks and exhibitions. Current water use per capita in the EU is around 160 L/p/d in residential buildings [12]. Applying additional standards and measures such as decreasing leakage in water supply networks, water-saving sanitary devices, and more efficient household appliances would reduce water consumption per capita from 150 L/p/d (average in the EU) to a low 80 L/p/d in the public water supply sector [13]. In the United Kingdom, water use per capita accounted for 142 L/p/d in 2020. By 2050, there is a planning assumption to reduce personal water use to 110 L/p/d [14].

A previous study by ElZein Z et al. evaluated the elements of water management approaches to decide which can be used in Egypt. The researchers interviewed the key stakeholders in the water sector in Egypt to validate their proposed approaches. The stakeholders supported knowledge dissemination, using water fees, and criticized converting wastewater into drinking water [15]. This research recommended increasing public awareness and establishing a public database for water knowledge [15].

1.4 Research Objectives

This research aims to analyze and classify globally applied modern methods and technologies to optimize water efficiency in buildings and urban environments. It presents the current situation of using these solutions in the Egyptian urban environment to improve water efficiency. Moreover, it discusses and answers the question of to what extent the globally applied methods and technologies can effectively solve the current water issues in the Egyptian built environment. Accordingly, it proposes an additional concept to optimize water efficiency in the Egyptian built environment.

2 Methodology

A comprehensive literature search was conducted using relevant keywords related to the research topic across various databases such as Science Direct and Google Scholar. The review encompassed individual observation and primary/secondary data sources, including scientific articles and reports on water efficiency in urban environments, with a specific focus on water efficiency in buildings and surrounding urban areas in Egypt. The selection criteria for articles included relevance to water efficiency concepts, availability, validity, language, data quality, publication date, and peer-reviewed status. The researcher categorized and organized the current techniques for achieving water efficiency in buildings and surrounding urban areas. Furthermore, an analysis and discussion of the effectiveness of these techniques was undertaken. Lastly, the researcher presented the current situation of water efficiency in Egyptian urban environments. Figure 3 outlines the steps followed by the researcher to achieve the research objectives.

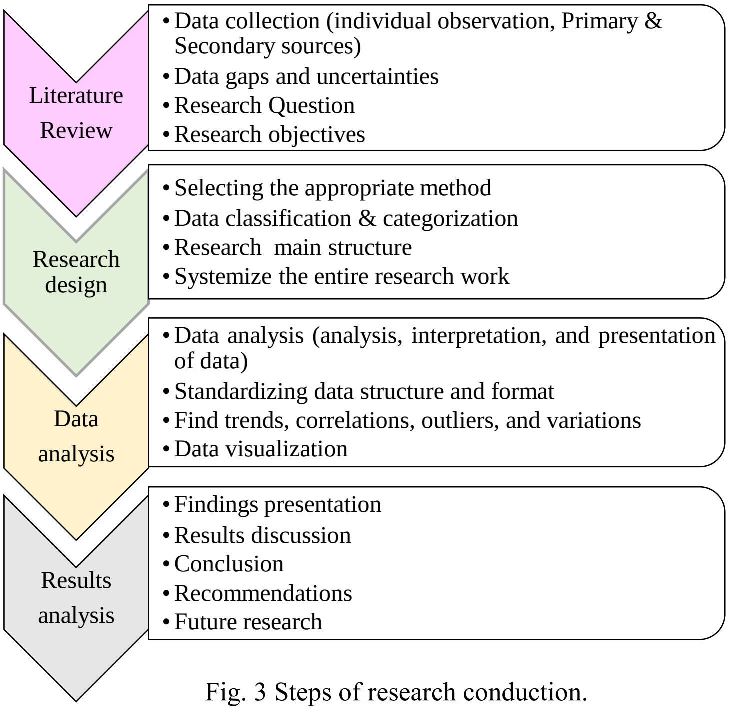

Fig. 3 Steps of research conduction.

3 Theory

3.1 Water Efficiency

Water efficiency is achieving a function, task, process, or result with a minimum water quantity. It also indicates the relationship between the amount of water required for a particular purpose and the amount of water used. Furthermore, it is a measure that reduces water use without affecting the benefits provided by water. Moreover, it is the intelligent use of water resources through water-saving technologies [16].

3.2 Water-Energy Nexus

Water and energy are highly interconnected and interdependent. All water services require an input of

Energy. Energy production consumes 15% of the world's total water withdrawals. The higher the water consumption, the higher the energy consumption and vice-versa. All phases of the tap water cycle (water supply, treatment, end-use, and disposal) consume energy in kWh/m^3, depending upon specific technologies applied at each phase of the tap water cycle [16]. However, buildings and urban communities consume a significant amount of tap water annually, which requires much energy for its supply, treatment, distribution, end-uses, and disposal [16]. Therefore, water utilities could reduce embodied energy by optimizing the efficiency of this water's supply, treatment, distribution, end-use, and disposal processes. Also, considering the factors that affect the reduction of embodied energy in all processes of both water supply systems and wastewater treatment systems, as shown in Table 1, as well as applying the technologies and tools to achieve water efficiency could help the designers of water and wastewater systems to achieve a significant decrease in water and energy consumption [16], which consequentially reduces the quantity of greenhouse gas emissions. i.e., every drop of water conserved reduces energy consumption and associated greenhouse gas emissions [16].

Table 1: Factors influencing the embodied energy in each stage of the urban water cycle.

Water supply	- Water type (Rivers, seawater) - Water quality (drinking, Irrigation, industrial) - Water location (surface water, underground water.
Water treatment	- Water pumping efficiency - Mixing efficiency
Water distribution	- Water pumping efficiency - Water leakage - Topographical characteristics
Water end-use	- Water heating and cooling - Extra water purification
Wastewater discharge	- Wastewater pumping efficiency. - Wastewater leakage - Topographical characteristics - Level of treatment and size of the facility

3.3 Water Efficiency Optimization

Many developed countries applied ISO 46001:2019, which defined three approaches to achieving water efficiency [17], as illustrated in Figure 4.

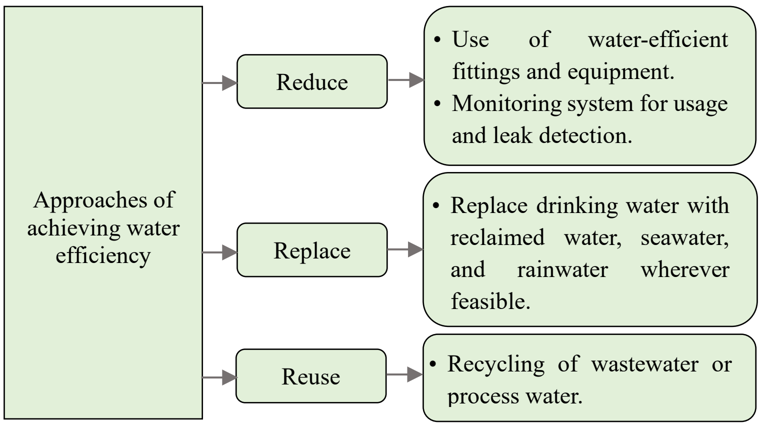

Fig. 4 Approaches to achieving water efficiency [17]

4 Strategies for Optimization Water Systems

As a result of the literature review, the researcher categorizes and organizes modern methods and technologies into three strategies to optimize water systems in urban areas. Figure 5 summarizes three strategies to optimize water systems in the urban zones.

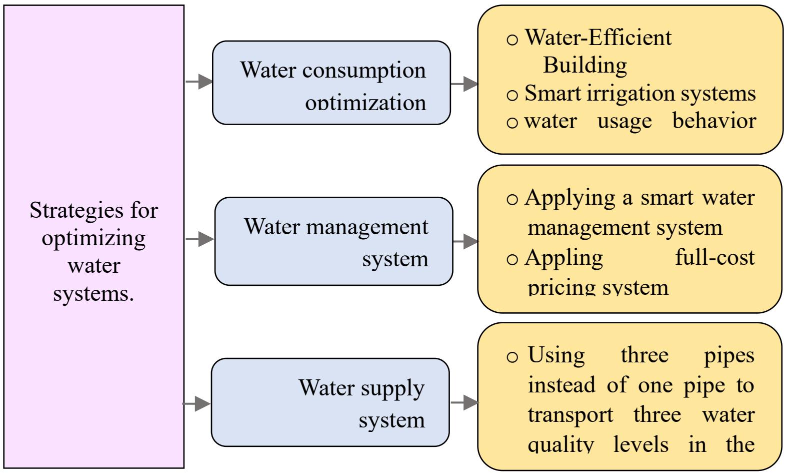

Fig. 5 Strategies for optimizing water systems

4.1 Optimization of Water Consumption

a. Water-Efficient Building (WEB)

Water-efficient buildings minimize water use, manage wastewater for reuse, conserve energy, and reduce costs [18]. Architects and building owners can achieve water-efficient buildings by using smart sanitary appliances and fittings such as toilets, showers, sinks, and urinal faucets. Also, home smart wash machines, dishwashers, and laundries consume less water than conventional models, as illustrated in Table 2. Moreover, early detection and quick repair of leaking taps and plumbing joints could decrease water loss.

Table 2: Percentage of water-saving by some smart sanitary devices [19].

Device	Toilet	showerhead	Sink faucet	urinal	Wash machine	Dishwasher
Save (%)	20 %	20 %	30 %	50 %	30 %	18 %

b. Smart irrigation systems

Plants' irrigation is the major consumer of freshwater in most arid countries. It consumes about 70% of all fresh water [20]. Therefore, adjusting the irrigation system is essential to reduce water consumption in plants' irrigation. Traditional flood irrigation systems are no longer suitable for arid countries, and the irrigation sector must benefit from modern technological advances [20].
Modern irrigation methods include drip, sprinkler, and surface/subsurface methods. They are used to irrigate farms, gardens, and individual plants. Smart irrigation systems can save 30% to 50% of freshwater compared to traditional irrigation systems [21]. The appropriate method selection depends on the type of crop grown, topography, and soil. A Modern irrigation system is either a weather-based method or an on-site soil moisture-based system. The appropriate solution depends on the geographical location, weather pattern, and landscape environment. For example, the modern irrigation system for gardens and landscapes has weather sense technology that provides watering based on site conditions such as land slope, soil type, sun/shade, statistics of watering times, and live weather feeds. It automatically adjusts the sprinkler controller to deliver the right amount of water to the plants. Using advanced technologies in water infrastructure to reduce water use in garden/farm irrigation will empower garden/farm owners to reach previously unimaginable levels of control and manageability of water.

c. Optimization of water usage behavior

People's water use varies greatly and depends on life patterns, users' attitudes, and the technical specifications of the water-consumed appliances. Therefore, optimizing people's awareness could improve water efficiency in buildings and urban environments. A previous study by S.H.A. Koop et al. [10] identified eight behavioral influencing tactics like knowledge transfer, increasing self-efficacy, social norms, framing, tailoring, evoking emotions, priming, and nudging that target household water conservation behavior. However, raising awareness among people is insufficient if there are no efficient management tools to incentivize them to change their attitudes toward achieving water efficiency in buildings and urban environments. For example, many incentives such as affordable, intelligent technologies (intelligent faucets, intelligent sensors, intelligent irrigation systems, and on-site alternative water reuse technologies) can be offered to achieve water efficiency in buildings and urban environments. On the other hand, if people cannot change their water consumption patterns and cannot react positively to fulfill water efficiency requirements, such as applying modern technologies to decrease water consumption. They must pay the total cost of their excessive water consumption.

4.2 Optimization of the water management system

A water management system is a systematic framework that includes a set of fundamental concepts, principles, resources, policies, processes, and procedures that are used by water authorities and water companies to achieve their objectives, such as financial success, safe operation, client satisfaction, and product quality [22]. However, achieving the goals of an efficient water system in the urban environment requires applying management plans and tools such as:

a. Applying a smart water management system.

- Apply intelligent water management technologies, including a wide range of hardware and software, to optimize water production, distribution, and consumption.
- Apply intelligent networks that interconnect water systems and integrate data, computation, predictive control, and communication technologies to improve water system performance.
- Apply intelligent technologies and Internet of Things (IoT) applications in water management systems could improve the transparency of water supply, predict issues, and respond immediately, reduce operational costs, automate connected meters, dynamic pricing, and payment systems, and optimize the use of water resources for the benefit of communities and ecosystems.

b. Applying full-cost pricing system

Prices are specified by the interaction between supply and demand in a competitive market [23]. Water price is determined either by the water authority (administrative) in many types of pricing, such as flat pricing, volumetric pricing, tiered pricing, and two-part tariffs, or by the market mechanism (market-based pricing) [23]. However, specifying the Water price depends on many factors, such as:

- Raw water source (seawater, deep groundwater, surface groundwater, rainwater, river water).
- The total energy cost, technology, facilities construction [23], [24], facilities operation and maintenance, and network infrastructure.
- Level of water quality (tap water or mineral water).
- Customer location: The longer the distance between the water plant and the customer's location, the higher the cost of water pumping and transfer pipes [24].

- Use type (diverse use requires diversified sizes of pipes and fittings. i.e., service connection costs can change with the change in the type of use (irrigation, drinking, industry, washing) [24]. It is noticeable that using volumetric pricing, which reflects the actual amount of water consumption by the customer, is more objective and acceptable than other fixed price categories because it incentivizes consumers to use less water. In this context, interest in full-cost pricing as a water management tool is growing across many regions in Asia, Europe, and North America [24]. Also, full-cost pricing includes all costs that society bears resulting from water production and consumption. However, full-cost pricing of water has many advantages, such as:
- Generate sufficient revenues that provide financial security for the water system and enable communities to maintain healthy financial conditions [24].
- Reduce the dependence of communities on subsidies.
- Promotes sustainable systems and ensures adequate water supplies.
- Increase consumer awareness of the water value and a perfect signal of water scarcity.
- Encourage water-efficient use and discourage the waste of water.

4.3 Optimization of Water Supply System

Currently, Egypt produces more than 11 billion m^3 of potable water to meet people's needs for drinking, cooking, washing, and personal hygiene. Indeed, a large part of this water is consumed for other purposes, such as garden irrigation, vehicle wash systems, industrial processes, and cleaning works that do not necessarily need potable water.

However, people usually consume one or more water types for varied reasons such as purpose, affordability, availability, health, taste, and specifications. In this context, purposes of water consumption could be specified and reclassified into three categories that satisfy the actual people's needs for multiple water quality levels as follows and shown in Figure 6:

a) Water Quality Level One (WQL-1): This is for drinking and cooking uses in residential buildings, food industries, and all facilities that need high-quality drinkable water that satisfies the desire of all people to use safe and healthy water. For example, most people in Egypt/around the world like to drink bottled mineral water.

b) Water Quality Level Two (WQL-2): This is for personal hygiene, laundry, showers, and other cleaning and washing processes that consume normal potable water.

c) Water Quality Level Three (WQL-3): This is for landscape irrigation, public facilities, and other uses that consume appropriate, sediment-free, and acceptable water quality but not necessarily potable water.

The proposed concept depends on using three pipes instead of one Pipe to transport and distribute the three levels of water quality as follows in Figure 7:

- Pipe A: transport and distribute Level One of water quality (WQL-1).
- Pipe B: transport and distribute Level Two of water quality (WQL-2).
- Pipe C: transport and distribute Level Three of water quality (WQL-3).

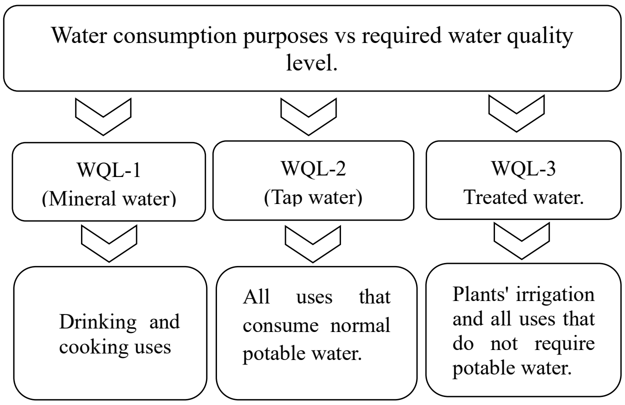

Fig. 6. Classifying water consumption purposes vs. required water quality level.

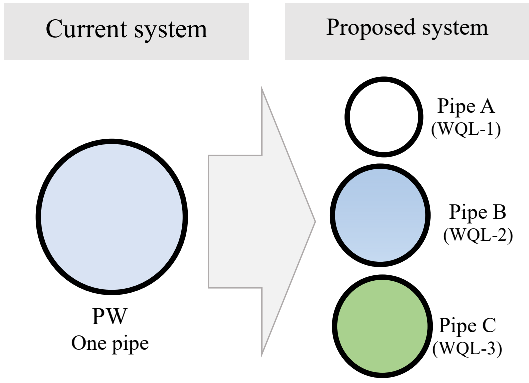

Fig. 7 Using three pipes instead of one pipe to transport water in the

5 Achieving water efficiency in the Egyptian urban environment

Egypt is pursuing different avenues to achieve its sustainable development goals for 2030 [15]. Currently, many modern tools and technologies are being applied (totally or partially) in the existing and new Egyptian urban communities. Moreover, real estate development companies in Egypt are moving quickly to embrace modern methods adopted by the "New Administrative Capital," which is a symbol of this transformation [25]. These modern methods include:

- Smart water management technologies such as the Internet of Things (IoT) and sensors to monitor and optimize water usage in buildings and public spaces, reducing wastewater and conserving water resources [26].
- Water quality monitoring
- Implementing educational and awareness campaigns and events about water conservation.
- An increased tariff system was applied as an effective tool to encourage water conservation.

In addition, Egypt Water, Sanitation, and Consumer Protection Regulatory Authority (EWRA) have initiated an initiative to rationalize drinking water by installing smart sanitary devices. Figure 8 presents four types of smart faucets to save water.

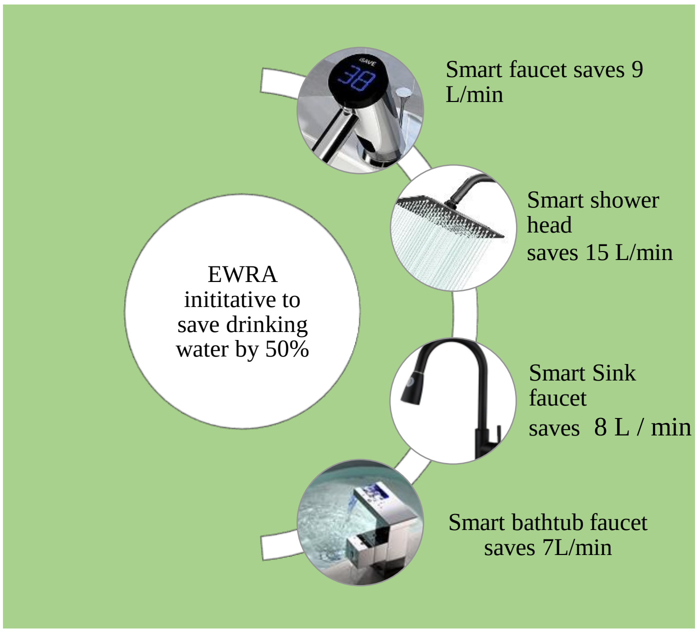

Fig. 8 EWRA initiative to save drinking water by installing smart faucets [27]

As a first stage, the EWRA initiative was implemented in several government buildings, including ministries and governorates, and in numerous mosques, churches, clubs, and schools. The findings demonstrated that these smart faucets saved more than 50% of the amount of drinking water consumed and contributed to reducing the consumer's water consumption bill [27].

Currently, Egypt produces more than 11.2 billion cubic meters of drinking water [5]. The total quantity of sold pure water was 8.5 bil.m^3, and the percentage of water loss was 27.9 % [5]. The widespread adoption of the EWRA initiative and early detection and quick repair of leaking taps and plumbing joints could decrease water loss, and an intelligent irrigation system can save vast quantities of produced drinking water annually. Figure 9 summarizes the potential to save drinking water by applying and generalizing the EWRA initiative and other technologies in all Egyptian cities and urban zones.

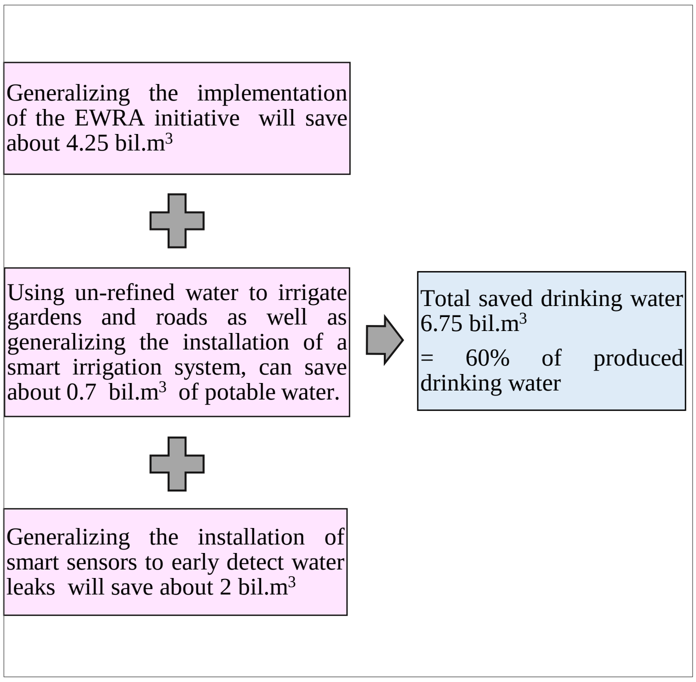

Fig. 9 Summarizes the potential to save drinking water through the widespread adoption of the EWRA initiative and other technologies.

The Egyptian holding company for water and wastewater applies volumetric pricing to sell potable water. The price increases with increasing water consumption; the average cubic meter price is 1.1 L. E / m^3, in addition to value-added tax (VAT), administrative fees, and wastewater fees [28]. The total saved drinking water is 6.75 billion. m^3. If this quantity is multiplied by the water (m^3) price, the sum can lighten a considerable economic burden on the state, which was the cost to produce and distribute this potable water. However, this huge burden could be lessened if the above strategies were applied. Moreover, the huge amount of fresh water saved could be used to irrigate more than one million agricultural feddan.

6 Results and discussion

This analytical study's results encourage applying three feasible and practical strategies to optimize water efficiency in Egyptian buildings and urban zones, as shown in Figures 5, 6, 7, 8, and 9. However, the continuous increase of modern technologies and tools to improve water efficiency in buildings and urban environments can motivate decision-makers to consider the effectiveness considerations of these technologies and tools to understand their pros and cons and consequently select the best alternative to achieve water efficiency. The researcher determined the following effectiveness considerations to understand the pros and cons of the above tools and technologies.

☐ The benefits of applying the three strategies shown in Figure 5 to optimize water efficiency in buildings and urban areas are summarized in the following Table 3.

☐

Table 3 presents the benefits of applying the above three strategies for optimizing water systems in buildings and urban areas.

Environmental level	- Reduce stress on the ecosystem. - Maintain aquatic ecosystems. - Preserving biodiversity - Mitigating climate change [29] - Reducing greenhouse gas emissions associated with heating, pumping, and treating water/wastewater.
Urban level	- Water-efficient buildings improve building operation performance and save water. - A water-efficient irrigation system saves water and improves property value.
Economic level	- Cost savings in resources such as water, materials, and energy. - Reduce infrastructure costs. - Reducing the need to build or expand expensive drinking water and wastewater systems. - Energy savings for pumping, treatment, and hot water. - Reducing costs for establishing businesses and supporting corporate - Making water bills more affordable. - The long-term savings from energy and resource efficiency can offset the initial cost.

□ Using three pipes to transport three levels of water quality will save significant amounts of water and energy and reduce the cost of additional purification processes because each Pipe will only transport the required amount of water for predetermined purposes. Moreover, high-quality drinking water will be available for everyone in Egypt to satisfy their desires and protect their health. An example of this concept is the NEOM future project in the Kingdom of Saudi Arabia, which will deliver mineralized water to every household to eliminate the need for bottled water [30].

□ Achieving the targeted benefits of applying the above modern tools and technologies, summarized in Figure 5, requires applying these tools and technologies in all existing and new cities and urban communities in Egypt, not being restricted to new Egyptian urban towns and neighborhoods. In addition, generalizing the EWRA initiative and other technologies in all Egyptian cities and urban zones will save about 60% of the currently produced potable water, as shown in Figure 9.

□ Applying a full-cost pricing system as a transparent and effective instrument to finance and manage a sustainable water system is confirmed by the American Water Works Association (AWWA), which recommended that the best practice for funding is that utilities be self-sufficient through rate revenue [24]. i.e., the full-cost price tool can support the state in financing all optimization plans of water systems, satisfying all people's needs for multi-levels of water quality, and financing subsidies for poor people. Finally, providing people with their needs of high-quality water (mineral water) through a public network would be a good alternative compared to installing home purifiers or purchasing mineral water bottles, which constitutes an additional cost and a heavy burden on a budget of many poor people as well as it will reduce the waste amount of water bottles. Moreover, improving people's awareness and making the non-excessive principle of water consumption a habit in their daily life patterns is necessary.

□ Table 4 summarizes recommendations for decision-makers, planners, urban designers, architects, water supply system infrastructure designers, and economic experts.

Table 4 summarizes some recommendations for the water supply system design and implementation participants.

Decision-makers	Making decisions, identifying solutions, and monitoring the implementation of strategic plans that target achieving water efficiency as a critical objective.
Urban planners	Create and implement plans to achieve water efficiency for cities, towns, and all urban areas' development.
Urban designers.	Using creativity and smart technologies to produce urban spaces/street designs that achieve water efficiency.
Architects	Architects can significantly influence how water is used and conserved by designing buildings that depend on installing smart water-efficient faucets and water-leaking sensors and considering rainwater harvesting and greywater recycling.
Infrastructure Designers	Preparing design documents for a water-efficient supply system and supervising the construction processes of the required infrastructure to achieve a water-efficient supply system.
Economic experts	Achieving water efficiency aims by providing economic assessments, cost, and tariff analysis, developing specific sustainable strategies under changing conditions, and providing performance indicators, metrics, efficiency analysis, and modernization techniques for optimization projects [31].

□ Finally, the research results added analytical data in new form and content about strategies for optimizing water systems to facilitate their assimilation into the existing knowledge. Also, the results filled the data gaps and uncertainty about the current situation of applying the modern tools and technologies of water efficiency in the Egyptian built environment.

Conclusion

This research analyzed and categorized the methods and technologies for optimizing water efficiency in buildings and urban environments into three strategies. This study concluded that most modern techniques and tools have been used (totally or partially) in some new and existing towns and neighborhoods in the Egyptian urban environment to improve water efficiency. The study recommends the widespread adoption of these tools and technologies in all existing and new cities and urban communities in Egypt to achieve targeted effectiveness and efficiency, not being restricted to some new Egyptian towns and neighborhoods. The application of the EWRA initiative and other technologies should be extended in all Egyptian cities and urban zones, saving about 60% of the currently produced drinking water. In addition, a full-cost price as a management instrument can support the state in financing all optimization plans for water systems, satisfying all people's needs for multi-levels of water quality, and financing subsidies for poor people. Finally, achieving the water efficiency principle is not only for saving water, money, and energy but also for using the amounts of saved water to irrigate new farms in the broad Egyptian desert. Future research will conduct a post-operation evaluation study of water efficiency in an educational building.

Conflict of interest

The researcher has no financial interest in declaring the content of this article.

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