Comparative analysis of greywater recycling and rainwater harvesting as supplementary water sources for conventional urban and tourist resort water supplies

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Abstract. Freshwater scarcity combined with high water demand from rapid urbanization, population growth, and changing consumption has resulted in increasing stress on urban water supply systems. Seasonal fluctuations in the population of tourist destinations are especially evident in tourist resorts. Greywater recycling and rainwater harvesting have been proposed as the most widely used valuable strategies to address water scarcity. By taking the conventional water supply system and the water supply of tourist resorts as examples, this study systematically compares and analyzes the advantages and limitations of greywater recycling and rainwater harvesting by enumerating the stress of water supply in different systems, discussing the benefits of both strategies and comparing the differences when using them for tourist destinations. The results showed that pumping systems or elevated tanks used to meet the water supply needs of high-rise buildings pose energy challenges. The water use characteristics of tourist resorts cause it to be closely related to the seasonal influx of tourists. Greywater recycling is more effective than rainwater harvesting in mitigating tourist resorts' water shortage problem. Suggestions for ways to implement these strategies for different regions are also given to make informed decisions about water distribution efforts. This study provides a reference for sustainable urban water resource management.

Keywords: Water Supply, Water Reclamation, Rainwater Harvesting, Tourist Resort.

1. Introduction

Water resources are an indispensable foundation for sustaining life and enabling socio-economic development. Clean and reliable freshwater availability is crucial for various uses in agriculture, commerce, domestic, and industrial production. Nowadays, the escalating demand for water due to population growth, urbanization, and changing consumption patterns presents a challenge to the sustainability of freshwater resources. According to a study, as of 2018, approximately 4 billion people around the world are affected by severe water shortages for up to one month each year [1]. Some areas with currently good water supplies are also considered to be at long-term risk [2]. And the challenge will continue to grow, with current water use projected to increase by 20% to 30% by 2050 [3].

One of the evident manifestations of freshwater scarcity is the mounting pressure on urban water supply systems. Rapid urbanization leads to high water demand that's outstripping the capacity of existing infrastructure. Studies reveal alarming trends in urban water supply pressure, with many cities

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experiencing water shortages and decreased water quality [3]. The situation is particularly pronounced in tourist resorts, which experience seasonal fluctuations in population due to the influx of visitors. Traditional water supply systems exacerbate the problem as they dispose of water resources after one use. It results in wasting valuable water and needing intensive energy and materials for treatment. This ever-increasing water consumption requires innovative approaches to effectively manage water supply systems. Alternative water supply technologies have been introduced to alleviate pressure on urban water systems, such as rainwater tanks and greywater recycling. By utilizing stormwater and treating greywater for non-potable purposes, both technologies can reduce water demand from traditional sources while being highly economical [4][5].

This study aims to examine the prevailing issues within current urban water systems and assess the effectiveness of alternative water supply technologies. Firstly, through the analysis of water use in tourist resorts and conventional water use cases, a comprehensive understanding of the water supply stress in different water supply systems is provided. Secondly, the benefits of greywater recycling and rainwater harvesting are comprehensively assessed by analyzing the impact of introducing them on the conventional water supply and tourist resorts. Finally, by comparing the feasibility and challenges of the two strategies in the specific water demand situation of tourist destinations, and incorporating feasible recommendations, this study aims to contribute to sustainable urban water resource management.

2. Characteristics and Types of Conventional Water Supply Systems

Conventional water supply systems have long stood as the foundational infrastructure that cities and communities have relied on to provide sufficient and safe water to their residents. Conventional systems draw raw water from surface water bodies and groundwater aquifers. Different treatment processes produce clean water that is stored or distributed to cities, satisfying diverse demand types influenced by factors such as population, location, climate, and economic activities. Generally, conventional water supply systems ensure equitable and reliable access to water throughout the serviced area and balance and manage fluctuations in demand, peak usage times, and any disruptions in the supply chain. Conventional systems have a proven track record of providing reliable access to water with strict health and safety standards for urban populations. Still, conventional water supply systems are vulnerable to some factors that lead to pressure on water supply demand.

2.1. Water pressure

A critical facet of water supply systems is maintaining adequate water pressure to ensure efficient and equitable distribution. Gravity-fed systems utilize the natural force of gravity to move water from higher sources to lower-lying areas. This design inherently provides a consistent supply pressure and steady flow of water based on the natural flow of water. However, the pressure may not be sufficient to serve areas with high-rise buildings or elevated terrain. For areas where natural gravity flow does not provide adequate pressure, supplementary pumping systems become necessary to boost the pressure in the distribution network and ensure that water reaches all areas, specifically high-rise buildings, and elevated terrain. Though essential for equitable water access, the increased energy demands associated with operating pumping systems or maintaining elevated tanks can pose notable obstacles. Balancing the benefits of improved pressure management with the need to address energy consumption is thus a key consideration in the deployment of such interventions. Water towers and elevated tanks are alternative ways to provide distribution system pressure, allowing gravity-based efficient water distribution without constant energy input. One example is in the tanks, which are economically advantageous for irregular demand patterns [6]. Overall, interventions such as pumping systems or elevated tanks could bridge the gap in pressure requirements but introduce energy challenges.

2.2. Surface water

Another factor that can significantly affect conventional water supply systems is water availability. Both surface water and groundwater are essential sources of conventional water supply needs. Surface water sources like rivers, lakes, and reservoirs are essential components of many conventional systems. For example, the population of Egypt is dependent on the Nile for all water needs [7]. They are susceptible to variations in rainfall and climate conditions. According to Abd Ellah et al. on the surface water of the Nile River, surface water availability was found to be easily affected by changes in rainfall and climatic conditions [7]. During periods of drought or reduced flow, the availability of surface water can be limited, affecting the reliability of the water supply. Overall, interventions such as pumping systems or elevated tanks could bridge the gap in pressure requirements but introduce energy challenges.

2.3. Groundwater

Groundwater aquifers provide another stable source of water for conventional systems. These underground reservoirs can store large volumes of water, which can be tapped during periods of surface water scarcity. Groundwater is more accessible to obtain than surface water because it can be directly extracted, which makes groundwater considered the preferred drinking water source worldwide [8]. However, over-extraction can lead to aquifer depletion and subsidence, creating long-term sustainability concerns. In addition, since the rate of recharge to groundwater will decrease with less precipitation, changing weather patterns with either altered precipitation or increased temperatures further compound these challenges [7].

Conventional water supply systems are characterized by their focus on meeting the consistent water demands of permanent populations. As described above, conventional systems ensure equitable distribution and reliable access through efficient water treatment, pressure management, and varying consumption patterns within the serviced area. As another particular case in water usage, tourist resorts face transient and seasonal fluctuations due to tourism, having different water supply pressures compared to conventional water supply systems.

3. Water Usage in Tourist Resorts

Tourist resorts are recognized for undergoing significant fluctuations in water usage that correspond to distinct seasons. The fluctuation pattern is largely dependent on the tourist population. In periods of heightened demand, such as during the summer months or holiday periods, tourist resorts experience a surge in water consumption due to the influx of visitors. These guests engage in a variety of activities that require water, including bathing, using toilet facilities, and engaging in water-related recreational activities. Furthermore, the range of services offered by a hotel plays an essential role in determining its water consumption patterns. Luxury resorts, offering luxury amenities like swimming pools and jacuzzis, tend to exhibit greater water requirements in comparison to more economical lodging options. In addition, tourists' preference for months with less precipitation could exacerbate the stress on urban water supplies, especially in water-scarce regions.

The study conducted by Rico-Amoros et al. focused on hotels in Benidorm—a prominent Mediterranean tourist city [9]. The investigation revealed that September witnessed the highest water consumption across all hotels in the town, which aligns with the height of the tourist season. During this period, a wide range of water-dependent activities, from beach visits to increased use of showers and amenities, contribute to the heightened demand. Conversely, the period spanning from November to February represents a time of minimal water usage in tourist resorts. These months are characterized by lower occupancy rates due to factors such as colder weather and the absence of major holidays. Some one-star hotels are even observed to close their operations during this lean period temporarily. As a result, the decreased number of guests translates to reduced water consumption for the resort. This cyclical fluctuation in demand underscores the significant role that occupancy rates play in shaping water requirements for the hospitality industry. Rico-Amoros et al. also noted that the availability of water-based recreational facilities often results in considerable discrepancies in water usage among hotels of similar star ratings [9]. Resorts equipped with swimming pools and lush gardens tend to consume more water compared to their counterparts lacking these features. This trend is attributed to the consistent need for water replacement due to evaporation and cleaning associated with pool maintenance, while gardens require regular irrigation to keep the landscaping vibrant.

Another fact that compounds these pressures is that tourists are more likely to visit during the dry season. Rainfall generally harms tourist numbers in both short and long-term scenarios [10]. Therefore, it is often observed that the period when tourism experiences peak water demand is also the period when the recharge of aquifers through precipitation is at its lowest. This synchronicity puts considerable pressure on available water reservoirs, exacerbating the vulnerability of water-scarce regions. The impact of this dynamic is particularly pronounced in regions with arid or semi-arid climates.

4. Impacts of Greywater Recycling and Rainwater Harvesting on Water Supply System

The pressing global issue of urban water supply stress arising from water scarcity underscores the immediate need for sustainable water management practices. These practices are essential to guarantee the responsible and efficient utilization of precious water resources. Currently, the most widely used valuable strategies to address water scarcity are greywater recycling and rainwater harvesting. Both practices have significantly relieved pressure on urban water supply systems by increasing water use efficiency and reducing pressure on freshwater resources.

4.1. Greywater recycling

Greywater refers to domestic wastewater that does not contain human waste. Common greywater sources include dishwashers, showers, and washing machines [11]. These sources generate large volumes of water and can offset a significant portion of non-potable water needs if adequately treated and reused. Greywater reclamation takes advantage of this resource potential through redirecting, processing, and reusing water that would otherwise go to the sewer. The treated greywater is suitable for a range of applications in landscape irrigation, toilet flushing, and industrial processes.

The treatment of greywater for recycling involves a series of processes to remove contaminants and impurities to render it suitable for non-potable uses. The treatment regimen typically includes physical, chemical, and biological processes. Filtration mechanisms remove larger solids and particles, followed by biological treatment technology to degrade dissolved organic matter and disinfection methods such as chlorination or ultraviolet treatment to eliminate harmful pathogens. Some systems incorporate advanced technologies such as electrocoagulation-electroreduction, ozonation process, or membrane filtration to achieve up to 90% purification [11]. Recent studies also highlight that green roofs and green walls serve as natural greywater treatment methods, similar to centralized solutions like constructed wetlands and sand filtration. Green roofs utilizing plant roots and porous media could substantially reduce total content of suspended solids, biological oxygen demand, nitrogen, phosphorus, chemical oxygen demand, and escherichia coli [12].

A multitude of instances showcase the effective adoption of greywater recycling systems and their positive impact on stress relief in water supply systems. For example, Australia has successfully implemented household greywater reuse through complete guidelines, and the current greywater reuse has achieved an annual saving of about 9.7×10^6 L water for the country [11]. Similarly, Jordan's new vertical-flow constructed wetlands for greywater treatment have achieved an estimated value of about US$ 100 per year for households by meeting a significant portion of their non-potable water needs [13]. This case also underscores the feasibility of this approach in arid regions.

4.2. Rainwater harvesting

Rainwater harvesting involves collecting rainwater from surfaces such as roofs and sidewalks, then storing and treating it for various non-potable water uses. The use of freshwater resources harvested in this way for domestic and agricultural use in arid regions has been documented since the earliest days of human civilization. Today, increasing industrial and domestic water demand has led most developing countries to adopt rainwater harvesting as a measure to reduce the need for freshwater sources. In some arid regions, including sub-Saharan Africa, rainwater is even used as drinking water [14].

Rainwater harvesting generally employs a variety of collection, storage, and treatment methods to maximize its capacity. According to Słyś and Stec, collection mechanisms include a roof catchment system where rainwater is channeled through gutters and downspouts to storage containers [15]. Storage options range from simple rain barrels to large tanks. Treatment processes depend on the collected stormwater's intended use and could include filtration, sedimentation, and disinfection to ensure safe water quality.

Rainwater harvesting is widely used in particular environments, such as conventional water supply systems and tourist resorts. In conventional urban systems, harvested rainwater can be used as a supplementary water source for non-potable uses such as landscape irrigation and toilet flushing. An example is presented by Słyś and Stec in a single-family housing complex in Poland [15]. The simulation model proved that using rainwater to flush toilets and irrigate gardens under both rainwater harvesting systems can achieve a water-saving effect of more than 50%, demonstrating the feasibility of integrating rainwater harvesting into urban infrastructure.

4.3. Cases in tourist resorts

Greywater recycling and rainwater harvesting are especially valuable in tourist resorts where water consumption fluctuates due to changes in visitor numbers. However, the application of greywater recycling emerges as a more effective strategy than rainwater harvesting in addressing water supply challenges within tourist resorts, substantiated by several key factors.

Firstly, the efficiency of greywater recycling is inherently linked to the amount of water consumption. Existing data reveals that tourists generally have a higher per capita water consumption than that of residents [16]. This disparity is particularly pronounced within hotels. As a result, given the height within hospitality establishments, greywater recycling holds greater promise in achieving significant conservation outcomes within resorts compared to residential areas.

Secondly, the energy consumption associated with greywater recycling is significantly influenced by the nature of the treated greywater. In tourist resorts, the composition of greywater primarily stems from showers, laundry facilities, and recreational water activities [16]. Notably, these sources yield greywater that is less challenging to treat in comparison to the kitchen water prevalent in typical residential settings. Kitchen greywater generally contains more organic matter and oil and poses more complex treatment requirements [11]. This distinction in greywater sources leads to lower treatment costs and logistical complexities within resorts, further reinforcing the viability of greywater recycling.

Thirdly, in locales characterized by abundant seasonal precipitation, tourists often choose to visit in the dry season to avoid consecutive days of precipitation [17]. The large number of tourists visiting in the dry season makes the water supply system unable to obtain effective freshwater replenishment from precipitation, which significantly limits the effectiveness of using rainwater as a supplement to the substantial water consumption demands. Moreover, storage tanks represent the largest cost in rainwater harvesting systems [18], the relatively high costs required for rainwater storage make it impractical for most regions to collect and store rainwater during the rainy season for subsequent use during the dry season's tourist peaks.

Finally, the viability of rainwater harvesting in year-round arid regions is highly constrained by the lack of precipitation, making it a solution with limited reliability to alleviate water supply stress. Therefore, although rainwater harvesting presents potential advantages, its effectiveness remains primarily confined to areas marked by continual year-round precipitation. Its effectiveness in countering water supply challenges is more apparent in areas where precipitation is abundant throughout the year, particularly for tourist resorts that experience pronounced occupancy peaks.

In summary, greywater recycling is expected to be more effective than rainwater harvesting in addressing water stress in tourist resorts due to higher water consumption per capita in hotels, the suitability of greywater sources, the limitations of rainwater harvesting during the peak tourist season, and the fact that rainwater harvesting is mainly applicable to areas with perennial precipitation.

5. Suggestion

Depending on the local land use type and water supply system, the practical application of greywater recycling and rainwater harvesting in the water distribution system cannot work to the same effect [19]. Therefore, sound water resource management strategies should be developed through careful assessment of water demand for different water supply categories. This comprehensive analysis provides a clear understanding of where and how water is being used to make informed decisions about water distribution efforts. Among other things, by quantifying the potential savings in greywater recycling and rainwater harvesting, specific target areas where these sustainable practices can be effectively implemented can be identified. This data-driven approach ensures that resources are allocated for optimal results, maximizing the impact of water conservation initiatives.

Given the dynamic nature of water demand in tourist destinations, attention should be paid to seasonal fluctuations that often occur in these regions. Not only to meet the average demand but also to consider the water supply system during the tourist season to ensure continuous water supply when citing greywater recycling and rainwater harvesting. This proactive approach prevents water shortages during periods of high demand and, through thoughtful planning and infrastructure design, maintains visitor satisfaction without compromising local water supplies. Integration with existing infrastructure is another critical aspect. Tailoring feasible seamless assimilation options to the specific needs of each destination can ensure that selected water-saving methods can be put to use at a lower cost. At the same time, when choosing between greywater reclamation and rainwater harvesting systems, considerations regarding water quality and treatment requirements should be prevented by conducting a thorough assessment of the suitability of the various technologies.

In pursuing sustainable water management, environmental issues are at the forefront of considerations, so the impact of energy consumption and carbon emissions related to the adopted technology must be thoroughly evaluated [20]. A balance must be made between water conservation goals and ecological footprint reduction to ensure that the methods chosen could minimize adverse environmental impacts while having water conservation as the goal. These ecological factors make the decision-making process more holistic and aligned with broader sustainable development goals.

6. Conclusion

This study provides a systematic analysis to demonstrate the benefits of rainwater harvesting and greywater recycling as an alternative water supply for cities and tourist destinations.

(1) Conventional water supply systems rely on drawing raw water from surface water bodies and groundwater aquifers. Gravity-based systems require pumping systems or elevated tanks to meet the demands of high-rise buildings or elevated terrain, which could introduce energy challenges. Surface water sources such as rivers and reservoirs are susceptible to variations in rainfall and climate conditions, and groundwater aquifers that offer a stable alternative have sustainability concerns due to over-extraction and changing weather patterns.

(2) The unique mode of operation of tourist resorts leads to specific water use patterns that are closely related to the seasonal influx of visitors. These fluctuations are mainly influenced by factors such as the number of tourists, weather conditions, and amenities offered by the resorts. Water use dynamics in tourist destinations underscore the need for targeted water management strategies.

(3) Greywater recycling and rainwater harvesting can significantly alleviate pressure on urban water supply systems while enhancing water use efficiency. Greywater recycling is a relatively more effective solution to alleviate water shortages in tourist destinations. The compatibility of greywater recycling with the higher water demands of tourist resorts, simplified treatment processes, and the ability to adapt to varying consumption patterns make it a more suitable and efficient strategy for addressing water supply challenges in these dynamic environments.

When introducing new strategies, a targeted water resource management strategy should be developed by assessing the local water supply system and water demand. Integration with existing infrastructure can help cities achieve water conservation at a lower cost. Safety issues such as water quality also need to be considered. Finally, a balance must be struck between water conservation goals and ecological impact. Building upon the insights obtained from this study, future research can benefit from interdisciplinary collaborations involving hydrologists, urban planners, climatologists, and social scientists. Collaborative efforts can provide comprehensive insights into the complex interactions between water systems and urban development.

References

[1] Du Plessis A and du Plessis A 2019 Current and future water scarcity and stress. *Water as an inescapable risk: current global water availability, quality and risks with a specific focus on South Africa* 13-25 Cham: Springer International Publishing

[2] Mekonnen M M and Hoekstra A Y 2016 Four billion people facing severe water scarcity. *Sci. Adv* 2 e1500323

[3] Du Plessis A 2023 Water resources from a global perspective In *South Africa's Water Predicament: Freshwater's Unceasing Decline* 1-25 Cham: Springer International Publishing

[4] Khan A S 2023 A Comparative analysis of rainwater harvesting system and conventional sources of water *Water Resour. Manag* 37 2083-106.

[5] Elhegazy H and Eid M M 2020 A state-of-the-art-review on grey water management: a survey from 2000 to 2020s *Water Sci. Technol* 82 2786-97

[6] Workeluel N, Saha P, Matiyas S and Mohanty T 2023 A comparative study on analysis and design of RC C elevated water tank using different country codes *Mater*

[7] Abd Ellah R G 2020 Water resources in Egypt and their challenges, Lake Nasser case study *Egypt J Aquat Res* 46 1-12

[8] Carrard N, Foster T and Willetts J 2019 Groundwater as a source of drinking water in southeast Asia and the Pacific: A multi-country review of current reliance and resource concerns. *J. Water* 11 1605

[9] Rico-Amoros A M, Olcina-Cantos J and Saurí D 2009 Tourist land use patterns and water demand: Evidence from the Western Mediterranean *Land Use Policy* 26 493-501

[10] Gricar S, Baldigara T and Šugar V 2021 Sustainable determinants that affect tourist arrival forecasting *Sustainability* 13 9659

[11] Vuppaladadiyam A K, Merayo N, Prinsen P, Luque R, Blanco A and Zhao M 2019 A review on greywater reuse: quality, risks, barriers and global scenarios *Rev. Environ. Sci. Biotechnol* 18 77-99

[12] Manso M, Teotónio I, Silva C M and Cruz C O 2021 Green roof and green wall benefits and costs: A review of the quantitative evidence. *Renew. Sust. Energ. Rev* 135 110111

[13] Abdelhay A and Abunaser S G 2021 Modeling and economic analysis of greywater treatment in rural areas in Jordan using a novel vertical-flow constructed wetland *J. Environ. Manage* 67 477-88.

[14] Nakin O, Ikegwuoha C, Ngubane Z and Walker M 2022 Assessing Water Quality from Roof Rainwater Harvesting Systems Aimed for Potable Use: A Case Study in the Eastern Cape Province, Nomlacu Rural Area, South Africa *Authorea Preprints*

[15] Słyś D and Stec A 2020 Centralized or decentralized rainwater harvesting systems: A case study *Resources* 9 5

[16] Estévez S, Feijoo G and Moreira M T 2022 Environmental synergies in decentralized wastewater treatment at a hotel resort *J. Environ. Manage* 317 115392

[17] Gricar S, Baldigara T and Šugar V 2021 Sustainable determinants that affect tourist arrival forecasting *Sustainability* 13 9659

[18] Rahman S, Khan M T R, Akib S, Din N B C, Biswas S K and Shirazi S M 2014 Sustainability of rainwater harvesting system in terms of water quality *Sci. World J* 2014

[19] Oviedo-Ocaña E R, Dominguez I, Ward S, Rivera-Sanchez M L and Zaraza-Peña J M 2018 Financial feasibility of end-user designed rainwater harvesting and greywater reuse systems for high water use households *Environ. Sci. Pollut. Res* 25 19200-16

[20] Wanjiru E and Xia X 2018 Sustainable energy-water management for residential houses with optimal integrated grey and rain water recycling *J. Clean. Prod* 170 1151-1166