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Research Article

Should we value rain harvesting more in Türkiye for mitigating precipitation extremes

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ABSTRACT

Mitigating precipitation extremes is a major issue due to destructive global warming and climate change. Heavy rainfall and drought have posed a threat to human life and ecology. That said, new strategies and new action plans are needed at local and global levels through needed cooperation from different stakeholders to handle the possible risks associated with precipitation extremes. Türkiye has become one of the most vulnerable countries involved in climate change due to its geographical location, rapid urbanization, and deforestation. Many forests have been destroyed to make room for agriculture, animal grazing as well as for manufacturing and construction. The impact has caused complications in landscapes. Precipitation extremes, such as heavy rainfalls and drought, are posing significant threats for many cities in Türkiye. In recent years Türkiye has faced a large number of extreme events regarding precipitation. In this line, the present study aims to explore the potential benefits of rainwater harvesting (RWH) in mitigating precipitation extremes by overviewing regulatory actions of rainwater harvesting and best practices worldwide. In addition an interview-based survey was conducted with domain experts in the water management field to better understand the current challenges of stormwater management in Türkiye and discuss the role of rainwater harvesting against precipitation extremes. The results of the study have shown that Türkiye has several problems with infrastructure to mitigate precipitation extremes, such as shortcomings in capacity and old water management systems, unseparated water collection and sewage systems, and lack of green infrastructure. In addition to urbanization, expansion in industry and tourism may cause water unavailability. The study has also indicated that many authorities around the globe try to boost RWH use by stipulating or encouraging RWH through incentives to save a large amount of water by implementing different projects. This research has argued that RWH promises several benefits thanks to its cost-effectiveness and contribution to water storage. Therefore, this study has recommended that policymakers should take immediate action against precipitation extremes by introducing new regulations, such as mandating rainwater harvesting for old buildings, industrial and touristic places. Preparing new guidelines and applying rooftop RWH systems that comply with Building Code requirements should also be considered for the widespread use of rainwater in rural and urban areas.

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INTRODUCTION

Environmental awareness is growing steadily worldwide due to confronting various environmental adversities [1]. Climate change and landscape utilization patterns are crucial concerns for urban water ecosystems and human life [2]. Since urbanization brings about a rapid increase in impervious land cover and deteriorates the quality of the ecosystem [3], proper use of resources is crucial for reducing environmental impacts, protecting the ecology, and sustainable development [4]. Proper management of water, which is an economic asset is also crucial [5]. Due to the depletion of natural resources and the deep impacts of climate change as well as rapid urbanization, the reuse of rainwater is of great importance for both meeting water needs and assisting with flood retention measures in urban and rural regions. Heavier rainfall events occur more frequently in the cities because of climate change [6]. Overloading of removal systems, sewage treatment plants and recipients of water flows increases the risk of floods [7]. Furthermore, contaminated stormwater (SW) runoff from urban environments carries several contaminants to water bodies, which poses a threat to the health of living beings and ecological systems [8]. Surface water is negatively affected by excess nitrogen via eutrophication and related processes [9]. Although SW is a significant hazard, it is also a promising resource [10]. Therefore, the utilization of rainwater has a growing interest around the globe.

In the literature, there are numerous studies, which mainly focus on the performance of RWH systems and improvement methods. Ünlükaplan and Tiğiz [11] aimed to design green areas by determining the necessary amount of irrigation water and the quantity of network water used in the green areas of Dikmen Valley stages in Ankara, in addition to calculating the potential amount of water to be acquired by rain harvesting from Dikmen Stream Basin. Buçak's study [12] emphasizes the importance of residential recycling systems and their benefits on water conservation and the necessity of implementation of such systems on mass housing projects by proposing an implementation example for an apartment in Kirklareli, Türkiye. Şahin and Manioğlu [13] analysed the amount of rainwater obtained using different building forms in different climatic regions comparatively. Teston et al. [14], addressed the high potential of rainwater harvesting systems for potable water savings and control of leakages and losses caused by carelessness or poor maintenance in buildings.

Due to water shortage in urban areas, high costs of developing new replacing surface water sources, inadequate groundwater supplies in arid and semiarid lands, and the unmanageable operation and maintenance costs of large piped water supplies [15], economical rainwater management systems have become more important recently. Therefore, the cost assessment of RWH systems is also one of the most important issues to be concerned. Mumtaaz Sayed and Sawant [16] conducted a financial

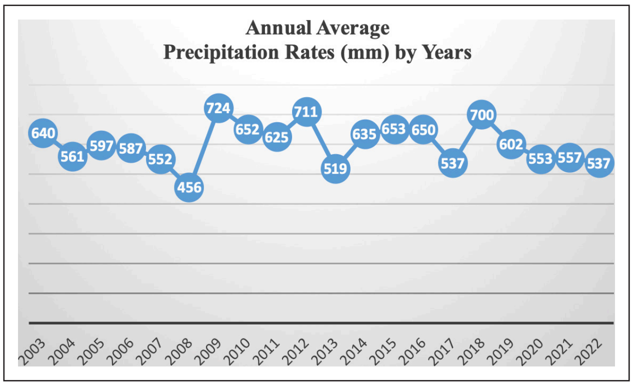

Figure 1. Annual precipitation rates by years (2003–2022) [20, 21].

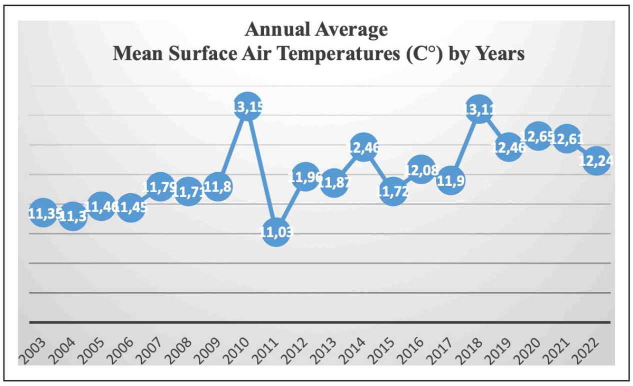

Figure 2. Annual average mean surface air temperatures by years (2003–2022) [22].

feasibility analysis of water conservation components considering lifecycle costs and operational savings in large mass housing projects. In their study, they presented a methodology of life cycle cost assessment of a unit RWH system for toilet flushing in an industrial site. Ghimire et al. [17], highlighted a feasible alternative design that has no pump and requires less operation and maintenance costs as well as tank refill volume.

Rainwater harvesting has a growing interest due to its potential in the world. In Türkiye, principles regarding the design and project planning of rainwater systems were regulated by the relevant legislation in 2017 [18]. It became obligatory to construct a rainwater harvesting system in any new building to be built on a parcel larger than two thousand square meters to meet building needs and garden irrigation in 2021 [19]. Although this precaution is of great importance for tackling the challenges of precipitation extremes, new actions are necessary for the reuse of water to mitigate the impacts of climate change and global warming. Figure 1 and Figure 2 show how annual average precipitation rates and surface temperatures change in Türkiye between 2003 and 2022. Figure 1 displays that there has been a drastic fall in annual average precipitation rates in the recent four years (2019–2022). On the other hand, according to Figure 2, before 2018, the annual surface temperatures were always below 12 C° except for 2010. However, the surface temperatures were measured above 12 C° in the last five years. This confirms

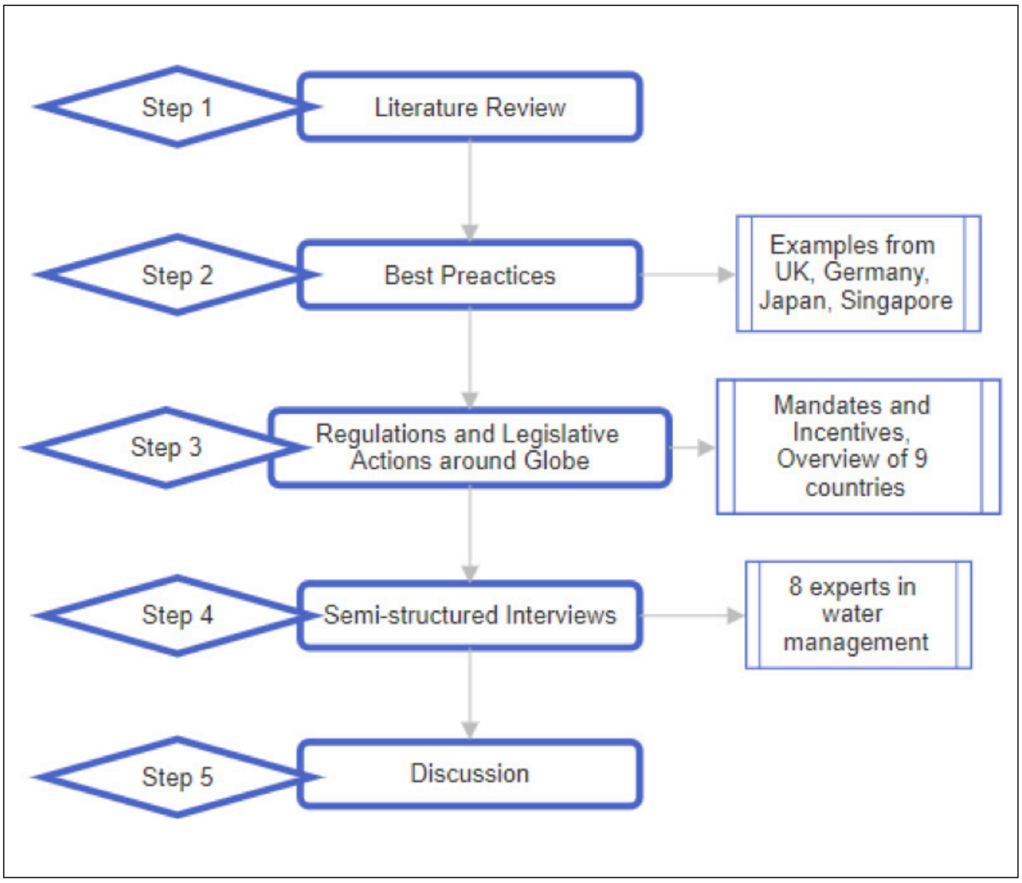

Figure 3. Flowchart of the study.

that while annual average precipitation rates have decreased, surface temperatures considerably have increased in recent years.

In addition to these climate impacts, precipitation extremes have occurred in the recent period. The precipitation value, which covers the period between 1 October 2023 and 31 March 2024, was above last year's precipitation, with a 41% increase compared to the same period of precipitation last year [23]. The year 2023 was recorded as the year of the most extreme weather events of all time in Türkiye, with 1,475 extreme weather events [24].

In this line, the present study aims to explore potential benefits of rain harvesting for mitigating precipitation extremes by overviewing best practices and legislative actions of rainwater harvesting worldwide as well as an interview-based survey with experts.

MATERIALS AND METHODS

The flowchart of the study is shown in Figure 3. After the literature review, best practices were determined to understand the real benefits of RWH systems worldwide. Then, legislative actions were overviewed for different countries to explore how RW is mandated or encouraged at the international level. Afterward, semi-structured interviews were held by eight different experts.

Best Practices

Rainwater harvesting systems offer several benefits to the built environment in different projects worldwide. Some best practices are explained by considering the scale of implementation and volume of water savings.

The 8,400 m^2 rooftop of a Sumo-wrestling arena in Sumida City, Japan serves as the catchment surface for the rainwater utilization system, which drains the collected rainwater into a 1,000 m^3 underground storage tank and uses it for toilet flushing and air conditioning [25].

In the United Kingdom, it was estimated that RWH adoption at the Velodrome project in London, a 73 percent overall reduction in potable water demand by using water-efficient fittings and rainwater topped up with recycled blackwater dirty water, one of the highest reductions in potable water demand on the Park [26].

In Germany, Frankfurt Airport has a big RWH system, which collects water from the roofs of the new terminal with an area of 26,800 square meters and helps to save approximately 1 million cubic meters of water per year [27]. Similarly, rainwater is collected and treated through rooftop water collection systems at Changi Airport, Singapore, which accounts for 28 to 33% of its total water used, resulting in savings of approximately S$390,000 per annum [28].

After the implementation of the RWH system, in HPCL Residential Colony, in Chembur Mumbai [29], site conditions drastically changed as follows: a) the recharging capacity of the bore well increased above 35000 liters per day, b) 50% of rooftop rainwater was harvested. c) yield capacity of the borewell increased from 10,000 to 20,000 liters per day, d) quality of groundwater enhanced and water level increased from 35 feet to 22 feet.

In Mexico City, RWH systems have been installed in households across the city through a notable initiative, the community-led Isla Urbana project, to mitigate water scarcity [30].

In the Caribbean, domestic RWH projects are being implemented to increase water supplies in islands lacking enough water and as a no-regret approach to adaptation to climate change [31].

These best practices are of great importance for contributing to sustainability and climate resilience. In addition, saving water reduces the cost of water supply.

Regulations on Rainwater Harvesting Systems Worldwide

As a global, long term and complex issue, climate change involves interactions between demographic, climatic, environmental, economic, health, political, institutional, social, and technological processes [32]. Since extreme weather conditions lead to water scarcity, drought, heat waves, and flash floods, all of which have significant impact on human life, infrastructures, and ecosystems [33], the adoption of cities to extreme weather conditions is challenging issue and handling hazards require a comprehensive and effective risk assessment [34, 35]. Therefore countries, states, and local authorities all over the world take action to manage rainwater issues. Table 1 indicates the RWH regulations in different countries around the globe.

It can be concluded that many authorities around the globe are trying to increase the use of RWH systems in different ways. While the RWH mandate is one of the most common approaches, some of the policymakers prefer to encourage RWH through different incentives and guidelines. The form of RWH systems, and their usage capacity are regulated in some regions. On the other hand, RWH is illegal in Colorado, USA, although it is encouraged in most of the countries.

Semi-Structured Interviews

A total of eight semi-structured interviews were held to collect further qualitative data. Professionals with invaluable water management experience participated in the survey to discuss the topics as follows: a) Threats of precipitation extremes, b) Major problems with infrastructural systems in mitigating precipitation extremes in Türkiye, c) The role of RWH against heavy rainfalls and drought. The background information of the interviewees is shown in Table 2.

Interview participants emphasized the major threats as flood due to heavier rainfalls and drought sourced by the decrease in water storage in dams in Türkiye.

I3 expressed this case as follows: '*The major threats regarding water are floods and drought in Türkiye. Although the country has moderate average annual precipitation, heavy rainfalls have occurred more frequently due to climate change recently, which cause destructive floods. On the other hand, precipitation can be lower compared to average values in some regions resulting in decreased water stored in dams.*'

Another threat was pointed out as water scarcity caused by unconscious industrialisation and touristic activities. I7 also highlighted this with the expression as follows: '*A large amount of water is utilized and released by the industry, which plays an important role in the quality and amount of water. Therefore, strict control of released water and effective use of rainwater are essential requirements for a well-established stormwater management strategy. Another key role belongs to tourism, one of the locomotives of the country. Each year, a large number of hotels are built in different regions, leading to increased water consumption of touristic cities. Existing water resources cannot even meet the needs of residents in such cities due to decreased annual precipitation.*'

After evaluating the expressions of interview participants, the major problems with the infrastructure in mitigating precipitation extremes in Türkiye were identified as follows:

- The stormwater collection and sewage systems are not separate in most of the residential areas. In the new residential regions, separate systems are being adopted, but central regions are very old and there are shortcomings in the renewal projects of infrastructure.
- The number of wastewater treatment plants does not suffice to meet the overall need.
- The capacity of infrastructural systems is inadequate. The number of RWH systems is insufficient.
- There is a lack of vegetation and green infrastructure. With increasing urbanization and the replacement of vegetation by impermeable medium, rainwater cannot infiltrate into the soil, and flow on the surface [36].
- Water is not efficiently used in agriculture. The farmers are unaware of new modern systems on how to efficiently benefit from rainwater.
- Despite the increasing population and number of houses, the number of new implementations improving stormwater management is limited.
- There are no regulations for using RWH in industrial and touristic areas, as well as existing houses and ones to be built in small parcels.

Rainwater harvesting systems were strongly recommended thanks to their promising and cost-effective solutions for surface runoff, water scarcity, and green infrastructure by all interview participants.

I6 argued: '*RWH systems are cheaper and easier to maintain. To ensure sustainable stormwater management and green infrastructure, RWH should be mandatory.*'

I8 pointed out: '*RWH systems stem from cisterns, widely used in ancient times. In applicable places, these cisterns can be renovated and also used for rainwater harvesting. The buildings with large roof space should be addressed for RWH. Unfortunately, there is a lack of awareness in such*

Table 1. RWH regulations in different countries around the globe

Location	Legislation on RWH systems and rain gardens	References
Australia	Regulations stipulate a new rainwater collection system or alternative water source in some states such as South Australia, New South Wales, and Queensland.	Yannopoulos et al., 2019 [36].
Brazil	RWH is encouraged by legislation in several cities as a policy of access to water in semi-arid cities. "One Million Cisterns" program, a federal government investment to enable access to water for families in the Brazilian semi-arid region by encouraging the construction of cisterns. Within the governmental program "One Land Two Waters" families of farmers get technologies and training to capture and store rainwater for agricultural use.	Teston et al., 2018 [14]; Mendonça, 2006 [37]; Gnadlinger, 2005 [38].
Germany	The use of stormwater infiltration systems is stipulated by water laws and regulations in Germany. There are strict regulations in drinking water standards. Household rainwater supplies are restricted to non-potable uses such as toilet flushing, clothes washing, and garden watering. In many towns and cities, grants and subsidies are given to encourage householders to construct rainwater tanks and seepage wells. Some form of RWH is mandated for buildings and houses in Hessen, Baden-Württemberg, Saarland, Bremen, Thuringen, and Hamburg.	Diekers et al., 2015 [39]; RWHb, 2023 [27]; Yannopoulos et al., 2019 [36].
India	Some form of RWH is mandated for buildings and houses in New Delhi, Indore, Chennai, and Rajasthan. The collection and storage of rainwater in earthen tanks for domestic and agricultural uses has also been very common for a long time. Rooftop RWH systems are mandated for newly constructed buildings in 18 of the 28 states and 4 of the 7 federal regions.	Yannopoulos et al., 2019 [36]; Marwas, 2010 [40].
Japan	Rainwater utilization is encouraged through tax breaks, subsidies, funds, policy loans, and other economic tools. Tokyo Sumida set up a rainwater utilization subsidy system for underground storage cisterns, medium and small storage cisterns, to boost the implementation of technology for rainwater utilization. Assistance programs have been introduced for rainwater cisterns and systems for rainwater seepage pits.	Fu, 2018 [41].
Malaysia	The government proposed RWH to mitigate the water crisis. Guidelines regarding planning, design, and installation of RWH, eco-efficient water infrastructure, and SW management systems were implemented by different governmental authorities.	Lee et al., 2016 [42].
New Zealand	Rainwater harvesting is mandated in several urban areas of New Zealand. While rainwater harvesting has long been the norm in rural areas that lack reticulated, yet it's still uncommon in New Zealand's urban areas. Rainwater systems must meet Building Code requirements, such as a requirement for adequate potable (drinkable) water to be provided for consumption, oral hygiene, utensil washing and food preparation.	Gabe et al., 2012 [43]; Rose, 2014 [44]; Branz Facts, 2024 [45].
Türkiye	Principles regarding the design and project planning of rainwater systems are regulated by the relevant legislation. RWH is mandated in any new building to be built on a parcel larger than two thousand square meters to meet building needs and garden irrigation.	Resmi Gazete, 2017 [18]; Resmi Gazete, 2021 [19].
UK	Manuals were developed about the design, construction, and management of RWH. Harvested rainwater can be used without a water abstraction license. A water abstraction license, which enables permission to get water at a certain amount from the water supply, is needed to abstract or transfer harvested rainwater.	EA, 2021 [46]; Yannopoulos et al., 2019 [36].
USA	Rainwater harvesting is not regulated by the federal government but rather it is up to individual states. Some states encourage the collection and use rainwater.Size of storage capacity is regulated in some states. Generally, commercial and residential applications are allowed in states with rainwater harvesting regulations. In Colorado, RWH is illegal.	PNNL, 2015 [47].

Table 2. Background information of interview participants

Interview participants	Description of expertise
1. Expert in environmental protection and infrastructure	Experience in waste water, economics of waste and waste management, climate change and ecosystems assessment and valuation, environmental legislation. Considerable experience in international projects
2. PhD researcher	Experience in urban policy planning and local governments Experience in project management
3. Water, dam & energy engineer	Recent studies on sustainable urban design systems Considerable experience in water resources management Experience in water & energy projects
4. Experienced senior lecturer	Head of Urban Water Management Unit Environmental awareness Experience in international project management
5. Civil engineer	PhD in Water Management Water Management Advisor
6. Stormwater technical director	Designing stormwater/wastewater treatment and management systems Green infrastructure for surface water
7. Associate professor	Water quality Water management
8. Professor in water resources	Experience more than 50 years in water resources and flood retention International experience in France and Algeria

systems. These systems do not require much investment and are easy to implement'.

Nonetheless, some important issues were concerned with efficient use of RWH in Türkiye. According to the I6 and I8, rainwater harvesting is worth implementing in regions with sufficient average annual precipitation. It is also feasible in regions with lower precipitation rates, but optimal design is of great importance due to potential extra operation and maintenance costs. According to the experts, it will not be worth implementing RWH systems for single houses, but will be worth for mass housing projects. The experts also highlighted importance of specific design in implementing RWH for different types of residential buildings in different regions.

RESULTS AND DISCUSSION

Due to its geographic location, rapid urbanization and increasing rate of deforestation, Türkiye has been deeply affected by climate change and global warming. Rapid urbanization and industrial developments considerably exploit and pollute freshwater resources [2]. In the near future, impacts may be more destructive. New strategies and new action plans are needed at local and global levels through needed cooperation from different stakeholders to handle the possible risks associated with precipitation extremes. Many forests have been destroyed to make room for agriculture and animal grazing as well as for manufacturing and construction. The impact has caused complications in landscapes. To tackle the challenges of precipitation, it became obligatory in Türkiye to construct a rainwater harvesting system in any new building to be built on a parcel larger than two thousand square meters to meet building needs and garden irrigation within the 'Regulation on Amending the Planned Areas Zoning Regulation', [19]. After this regulation was introduced, different projects were launched to promote rainwater utilisation. For example, within 'İzmir Sponge City' project, İzmir Metropolitan Municipality aims to include 5000 buildings in the incentive system with 5000 polyethylene rainwater harvest tanks [48]. However, this regulation may not be enough because of shortcomings in the current infrastructure and limited scope of buildings.

The study discussed several problems with the infrastructure, such as low quality of water due to a lack of stormwater plants and separate systems for SW collection-sewage removal, insufficient RWH, and shortcomings in green infrastructure and vegetation. It is seen that policymakers in Türkiye need to consider many precautions to mitigate precipitation extremes. The increasing number of mass housing projects, old and limited infrastructure and unavailability of separate stormwater management systems make it difficult to overcome challenges regarding heavy rainfalls. Wastewater may find its way into the receiving waters through stormwater sewers even in separate sewer systems due to cross-connections, illicit connections, overflows, and leakages through broken sewers [49]. If the systems are not separate, contamination is much higher. The local authorities and municipalities should give much more importance under the guidance of the government to replace current old systems that lack resilience against stormwater. The Delegation of the European Union to Türkiye [50] has funded many projects on the reuse of rainwater, and wastewater, and the construction of new wastewater treatment plants. Such funding schemes could be well-informed and promoted to encourage the municipalities and relevant authorities.

Although there is a mandate for RWH use in particular new buildings in Türkiye, there is no obligation for existing buildings to be constructed for housing, industry, tourism, etc. Furthermore, residential areas are very close to the industrial regions. A large amount of water is consumed by the industry and tourism sector, leading to higher water demand and water scarcity in cities close to industry and hotels. Existing water resources do not suffice to meet the needs of residents in many cities due to higher water demand and lower annual precipitation rates sourced by climate change. Therefore, the RWH mandate should also be considered not only for new buildings but also existing ones, especially for industrial areas and touristic regions. Furthermore, introducing new guidelines, and subsidies would be good alternatives to boost rainwater utilisation. Rooftop RWH systems can be also encouraged and manuals can be developed for better use of RWH systems, which comply with the Building Code requirements.

Overview of best practices and results of interview RWH shows itself a cost-effective system for mitigating precipitation extremes. In the literature, many studies have also confirmed their feasibility. Tanik [51] argued that the investment and operation costs of such systems are usually low. Bashar et al. [52] showed that payback periods of installation and maintenance costs of RWH vary within 2–6 years depending on the topographic and climatic conditions.

Although Türkiye has a moderate annual precipitation rate, precipitation extremes pose a major threat, which can result in destructive floods and drought in Türkiye due to drastic changes in peak values. Water scarcity may be one of the major problems due to decreased dam storage, and uncontrolled water use by the industry and tourism sector. This can also lead to several problems in agriculture. Water is ineffectively used, and people are not aware of the potential benefits of RWH systems in arid regions.

CONCLUSION

This study investigated the potential benefits of RWH for mitigating the impacts of precipitation extremes in Türkiye by overviewing regulatory actions and best practices as well as an interview-based survey. Due to the deep impacts of climate change, deforestation, and improper land use, Türkiye has been suffering from precipitation extremes. Increasing population and uncontrolled urbanization patterns have also resulted in numerous infrastructural problems, especially in metropolitan cities, such as Istanbul, Ankara, and İzmir. Therefore, water management is one of the challenging issues to be considered by authorities at the local and national levels. Rainwater harvesting has growing interest worldwide as it offers cost-effective solutions against precipitation extremes. There is a plenty of regulatory and legislative actions, which have been taken in different cities around the globe. Turkish government also implemented a new regulation which mandates RWH for particular newly constructed buildings, but further actions are needed to solve current and potential infrastructural problems in existing urban areas. Local authorities should also pioneer rainwater projects. For instance, making the practice of rain harvesting in İzmir City widespread in local governments may provide benefits throughout the country. Similar projects will boost rainwater utilisation. On the other hand, there is no RWH mandate for existing buildings and new buildings to be built in small parcels. Surface runoff will be a threatening problem in central and crowded regions since the amount and quality of water released to the infrastructural system are not well controlled. Therefore, the rule of the RWH mandate could also be applied to existing buildings. As the use of RWH may not be feasible for single houses due to investment and operation & maintenance costs, a mandate could be applied for groups of single houses. Mass housing projects are spreading all over the country. In addition, there is also a great expansion in industrial and touristic buildings, which leads to higher water demand. RWH systems with appropriate designs would be good alternatives for mitigating precipitation extremes.

In arid regions, RWH utilization is of great importance for the efficient use of rainwater and increasing harvest. Encouraging farmers to use RWH systems could decrease the need for exporting agricultural products. To obtain optimum efficiency from such systems, local authorities should find ways to separate stormwater collection and sewage systems for crowded urban regions. This is also needed to implement new water treatment systems to increase water quality. Applying for EU support with well-prepared projects would be a good option. The number of projects can be increased with the help of relevant public organizations and successful local authorities with valuable experience in such projects.

Although the research focus was only on Türkiye and further research that involves more countries may yield better results, the implications of this study are important to understand the potential problems with infrastructure against precipitation extremes and the benefits of RWH systems for handling challenges in developing countries.

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DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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