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# SOFT PATH WATER MANAGEMENT IN DRY AND ARID REGIONS OF THE ARABIAN PENINSULA BY RAINWATER HARVESTING

**Amin, M.T., A.A. Alazba and U. Manzoor**

Alamoudi Water Chair,
King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia

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## ABSTRACT

Saudi Arabia has limited renewable water resources and the groundwater is the main source of water in Saudi Arabia which. With an arid climate, it receives about 50-100 mm/year of rainfall in Central, Eastern and Northern regions. There are few studies investigating the future regional climate change and some has predicted a decrease in precipitation but with extreme climate events such as flood and stormy rainfall events. Authors have evaluated the thirty-one years record of the rainfall in different parts of the Kingdom and found an increasing trend in annual maximum daily rainfalls at investigated locations signifying the more extreme rainfall evens and resulting floods of short-durations. A brief review of the Rainwater Harvesting and Management (RWHM) practices in the Arab region and the current use of rainwater in Saudi Arabia is presented and keeping in mind the climate impacts on the water resources, authors have suggested rooftop RWHM as a soft-path water management strategy to avoid short-term flooding problems in urban areas. Cooperation between government and non-government sectors is also recommended for successful implementations of small-scale, decentralized and cost-effective practice of RWHM at individual/community levels.

**Keywords:** Climate Change, Rain Intensities, Rainwater Harvesting, Soft-Path

## 1. INTRODUCTION

Natural water resources in Saudi Arabia, like in other arid countries, are limited. There is also a lot of pressure on these resources due to alarming rates of increase in demand for irrigation (Al-Turbak, 1999). In many parts of the Kingdom, especially in Central, Eastern and Northern regions, groundwater is available in huge quantitiessatisfying more than 90% of its water demand. It is estimated that the total groundwater storage in the Arabian Peninsula is 80000 km$^3$ (Rasheeduddin *et al*., 2001) and the total groundwater reserve in Saudi Arabia is estimated to be 2259 billion m$^3$ (Alsharhan, 2003). Desalination meets 50% of the domestic water demand.

The climate of Saudi Arabia is mostly arid with an average rainfall ranging from 80 mm to 140 mm. The southwestern region receives the summer rainfall and the rainfall is highly variable sometimes due to high rainfall events (Elagib and Abdu, 1997; Alkolibi, 2002). Due to the increase in agricultural demand in these regions, more and more groundwater is being pumped every year. With this water scarcity in Saudi Arabia, knowledge of the impacts of climate change on its water resources is important for an efficient water future water management. There are few studies investigating the impacts of climate change in the region.

Ragab and Prudhomme (2002) investigated future climate changes by the 2050's and estimated a decrease in precipitation by 20-25% and an increase of 1.52.5°C

**Corresponding Author:** Amin, M.T., Alamoudi Water Chair, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia Tel +96614673737 Fax: +96614673739

in temperature over Saudi Arabia. Alsharhan (2003) estimated a total water stress between 1520-4947 million $m^3$ at a temperature increase of 1 and 5°C, respectively, due to climate change over twenty-one locations in Saudi Arabia. Alkolibi (2002) also discussed the effects of precipitation decrease on water resources of the country.

The Intergovernmental Panel on Climate Change (IPCC) in its final report predicted that annual mean changes of precipitation over Saudi Arabia for the years 2090 to 2100 relative to 1980 to 1990 will increase slightly over southern, middle and eastern regions with values equal or less than 0.1 mm $day^{-1}$ (Solomon, 2007). A slight decrease in precipitation (less than 0.1 mm/day) is predicted over northern Saudi Arabia by the end of the 21st century (Solomon, 2007). Similarly, changes in annual runoff show slight increases by 0.1 mm/day for most of Saudi Arabia, except a small portion of the northern region.

In short, some models reviewed by the IPCC predict a trend of precipitation increase in the Arabian Peninsula including Saudi Arabia. This increase in rainfall could arrive in concentrated, short and intense precipitation events, which could lead to a higher risk of flash floods and might have negative consequences on aquifer recharge affecting already stressed country. In this study, authors have investigated the similar trend of climate change over past 3 decades based of the weather data in few of the cities of Saudi Arabia and recommended Rainwater Harvesting and Management (RWHM) as soft-path sustainable water management strategy to cope with the future climate change.

## 2. MATERIALS AND METHODS

The precipitation record of about three decades (1980-2010) for thirteen cities of Saudi Arabia was investigated including the daily total, minimum and maximum rainfall. These stations cover almost all of the districts of the country except Ha'il, as shown in **Fig. 1** (three-layered map of Saudi Arabia showing the topography and districts (ElNesr *et al*., 2010).

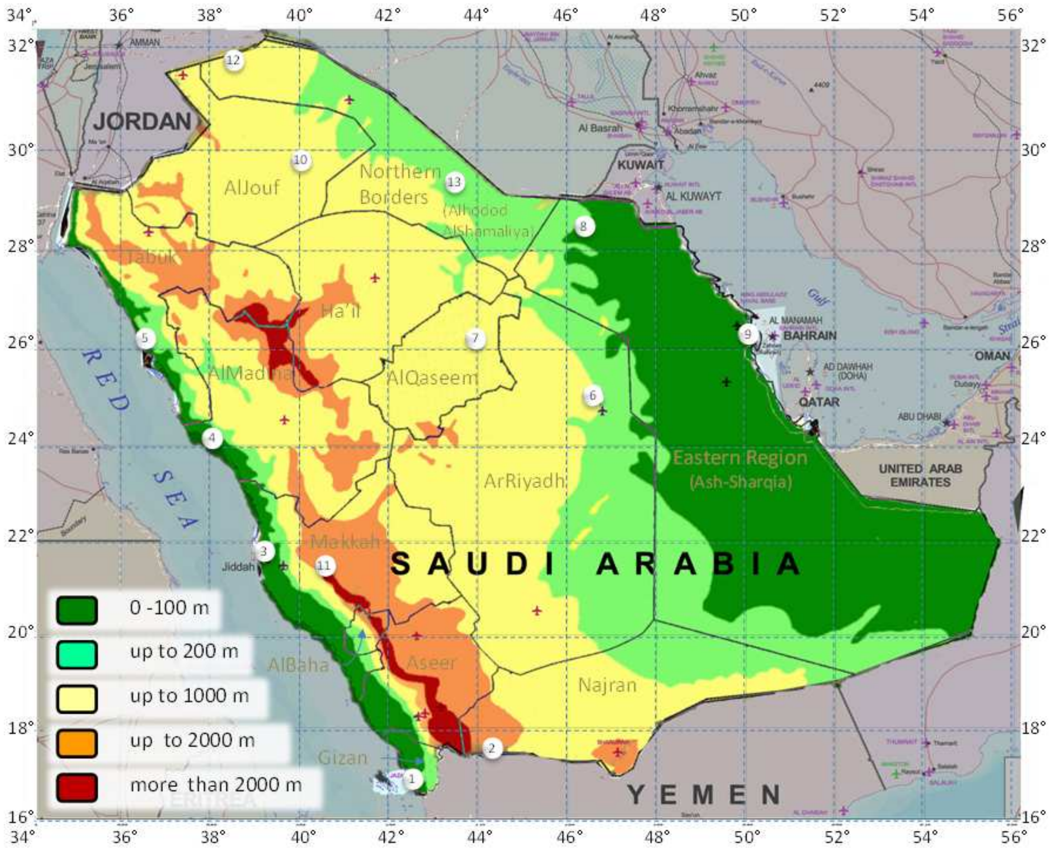



**Fig. 1.** Three-layered map of Saudi Arabia showing the districts and 13 investigated locations

The coordinates (latitude and longitude) of the investigated weather stations along with the altitude (in meters) are presented in **Table 1**. The magnitudes of the trends of rainfall (derived from the slope of the regression line) were calculated using the least squares method.Both time series and regression analysis were performed for statistical significance of the data and Durbon-Watson (D-W) co-efficient (used to test for autocorrelation (Montgomery *et al*., 2001)) was used to validate the analysis. The PHStat software in Microsoft Excel 2007 was used to calculate the D-W test statistic 'D', the value of which should be close to 2.

## 3. RESULTS

**Figure 2** represents the linear regression models for the annual maximum daily rainfall in Gizan and Rafha. In **Fig. 2**, solid and dotted lines represent the regression model lines for the annual maximum daily rainfall for Gizan and Rafha, respectively. In case of Gizan, maximum increase in the annual maximum daily rainfall with a slope value of about 1.30 ('D' being 2.2 as shown in **Table 2**) among the 13 investigated cities was observed over a period of 31 years (1980-2010). Data is also presented for another city (Rafha) where the minimum increase in the annual maximum daily rainfall was observed over a period of 31 years (1980-2010) with a slope value of about 2%.

The records for the total annual rainfall do not show any signs of increase for seven cities including AlRiyadh, AlQaseem, AdDhahran, AlJoug, Taif, Turaif and Rafha in precipitation in 31 years of study period (1980-2010).

**Table 1.** Detailed information of the thirteen meteorological stations

| City (District) | Station coordinates<br>Latitude ($^O$North) | Longitude ($^O$East) | Altitude (m) |
|---|---|---|---|
| Gizan (*Gizan*) | 16.54 | 42.35 | 3 |
| Najran (*Najran*) | 17.37 | 44.26 | 1210 |
| Jeddah (*Makkah*) | 21.30 | 39.12 | 17 |
| Yenbo (*AlMadina*) | 24.09 | 38.04 | 6 |
| AlWajh (*Tabuk*) | 26.12 | 36.28 | 21 |
| AlRiyadh (*AlRiyadh*) | 24.63 | 46.77 | 624 |
| AlQaseem (*AlQaseem*) | 26.18 | 43.46 | 650 |
| AlQaisoomah (*Eastern Region*) | 28.32 | 46.13 | 358 |
| AdDhahran (*Eastern Region*) | 26.16 | 50.10 | 17 |
| AlJouf (*AlJouf*) | 29.47 | 40.06 | 671 |
| Taif (*Makkah*) | 21.29 | 40.33 | 1454 |
| Turaif (*Northern borders*) | 31.41 | 38.40 | 818 |
| Rafha (*Northern borders*) | 29.38 | 43.29 | 447 |

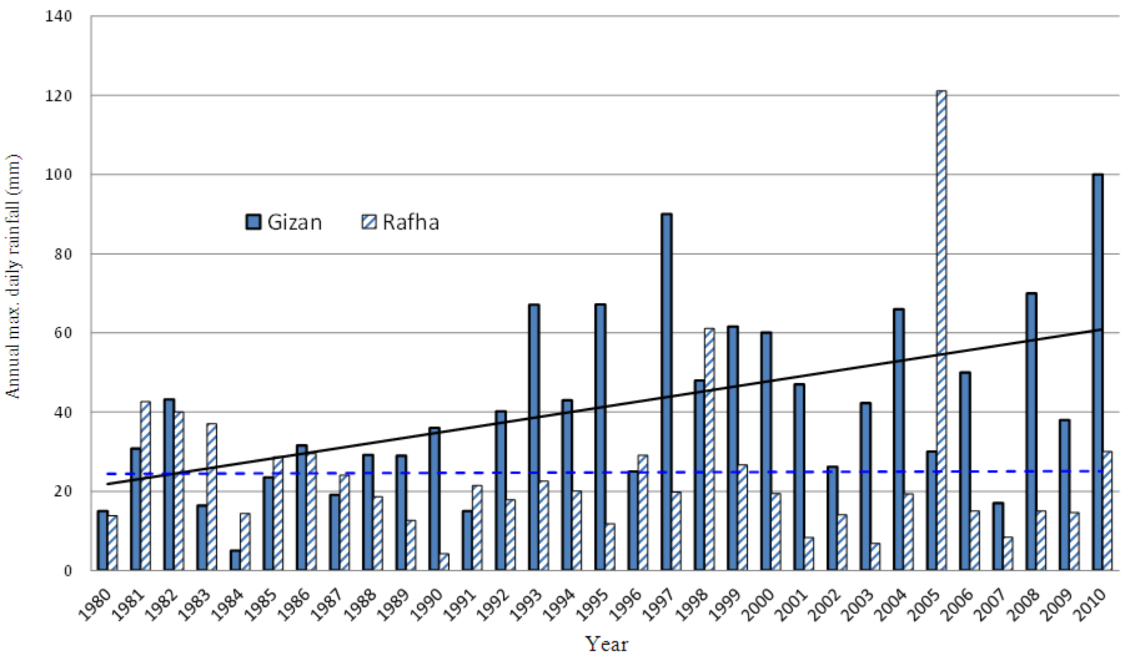



**Fig. 2.** Linear regression models for the annual maximum daily rainfall in Gizan and Rafha 1980-2010

**Table 2.** Slope and 'D'values for cities having regression lines with increasing maximum daily rainfall

| City | Slope values | D-W co-eff. |
|---|---|---|
| Gizan | 1.30 | 2.200 |
| Najran | 0.72 | 1.937 |
| Jeddah | 1.01 | 2.076 |
| Yenbo | 0.52 | 2.063 |
| AlWajh | 0.41 | 1.641 |
| AlRiyadh | 0.40 | 1.764 |
| AlQaseem | 0.40 | 2.132 |
| AlQaisoomah | 0.30 | 1.863 |
| AdDhahran | 0.29 | 2.161 |
| AlJouf | 0.25 | 1.616 |
| Taif | 0.24 | 1.822 |
| Turaif | 0.06 | 2.413 |
| Rafha | 0.02 | 2.008 |

There were, however, signs of increased rainfall with respect to the annual maximum daily rainfall, during this period, as is clear from the positive slope values, shown in **Table 2**.

For the remaining six cities, an increase in annual total rainfall was also seen along with increasing annual maximum daily rainfall over the investigated period of 31 years during 1980-2010 (results not shown).

## 4. DISCUSSION

Water management in Saudi Arabia is facing major challenges due to the limited water resources and increasing uncertainties caused by climate change. To investigate the existence of any signs of climatic changes in Saudi Arabia, the rainfall records of the thirty-one years of period (1980-2010) were analyzed for thirteen cities the rainfall trend in the whole Kingdom covering the wide areas of the country. The magnitudes of the rainfall trend were derived from the slope values of the regression lines and were supported by the Durbon-Watson statistic. An increased annual total rainfall trend was observed in six cities while an increasing trend in annual maximum daily rainfall in thirteen cities was observed. These rainfall trends highlight the higher rainfall intensities or rainfall with longer duration in addition to the variability of climate pattern in different cities of the same district and in different months of the years. The resulting floods of short-duration due to increased rain intensities have caused more damage in well-developed cities and urban centers in recent years.

Most visible effects of climate change in Saudi Arabia include the increased flooding and prolonged droughts. Although, the rainfall is not high in this region but the increased rain intensities has resulted into severe short-duration floods and damage in well-developed urban areas. **Figure 3** shows some of the photographs showing the aftereffects of extreme climate events due to high rainfall intensities with longer durations. In one of the several cases, it has even resulted four deaths in Kingdom's second largest city (Jeddah) due to the flooding caused by high intensity rainfall of longer duration (AlJazeera, 2011). One of the reasons for the resulting damage due to short-duration flooding could be the designing of the drainage systems in these cities which is based on dry weather of the country. So, a single rainfall event of higher intensity or longer duration can destroy the infrastructure and cause the economic disaster. The results of the analysis of this study indicate that an appropriate soft-path water managementpolicy should be implemented androoftop RWHM can provide one such solutionto respond to the higher rain intensities of longer duration to avoid short-term flooding situations described in **Fig. 3**.

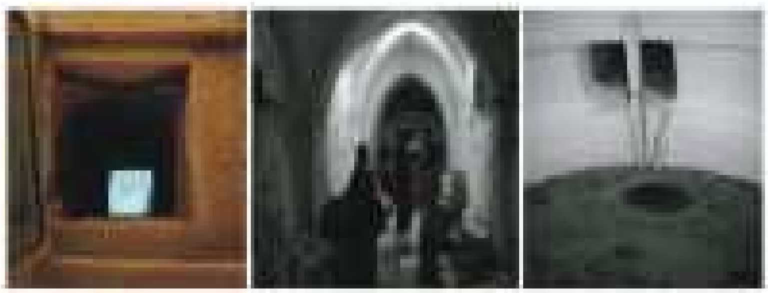
In the twenty-first century we can no longer ignore costs and concerns associated with centralized systems. The old water development path or simply hard path approach is increasingly recognized as inadequate for the water challenges that are faced by experts in this field. The soft path recognizes that investments in small and decentralized systems such as rainwater harvesting systems can be just as cost-effective as investments in large, centralized systems for example dams. One of the soft path decentralized solution being implemented in many developing countries is RWHM (Amin and Han, 2007).

Evidence of ancient water harvesting systems appears throughout the Arabian Peninsula (Myers, 1975). The first water harvesting system was built around 4500 B.C. in Iraq. It is known that terracing systems were used to supply water for pilgrims and caravans travelling from the Arabian Gulf to Makkah. Evidence of these systems can still be seen today along some desert roads throughout Saudi Arabia. There existed a rich culture and tradition of harvesting rainwater in this region as was revealed by the presence of underground cisterns in old city of Jeddah, Saudi Arabia (Lancaster, 2010). The roof would be swept off before the rains and the rainfall would be directed to downspouts taking the water to the huge basement cistern (**Fig. 4**).

**Figure 4** Different views of abandoned underground rainwater cistern in old Jeddah Recently, there has been renewed interest in traditional water harvesting techniques through the use of new revolutionary technology and innovations.

(a) (b) (c)

**Fig. 3.** Short-duration floods due to extreme rainfall events in urban areas of Riyadh, Makkah and Jeddah (January 2011) (a) Riyadh, (b) Makkah, (c) Jeddah



(a) (b) (c)

**Fig. 4.** (a) Cistern opening, (b) Section view, (c) Inlet and outlet

(a) (b) (c)

**Fig. 5.** Small rainwater dams at different locations in Riyadh, Saudi Arabia (a) Al Alab Dam, (b) Al Muzaira Dam, (c) Al Hareeq Dam

RWHM has been revived and have proven to be efficient methods of water utilization and is currently in use in the countries of the Arabian Peninsula. Terracing as means of rainfall utilization and soil conservation is extensively used in the mountainous areas of southwestern Saudi Arabia. In Saudi Arabia, an elaborate terrace system is being used in the upstream catchments of wadiBishah in the southwestern region. It has been estimated that rainfall harvesting techniques can be used into this area to meet domestic and livestock water demand (Abdulrazzak, 1992).

There is an on-ogoing King Fahd's Project for rainwater and runoff harvesting and recharge techniques in the Kingdom of Saudi Arabia in order to guarantee water for the inhabitants of villages and desert areas as well as for their livestock and agricultural production and to minimize the migration from villages to the already overcrowded cities due to water scarcity and low agricultural production. Rather than migration, people may also resort to modify the dwelling environments by adapting strategies to optimize the utility of available water by harvesting the rain (Pandey, 2001; Pandey *et al*., 2003).

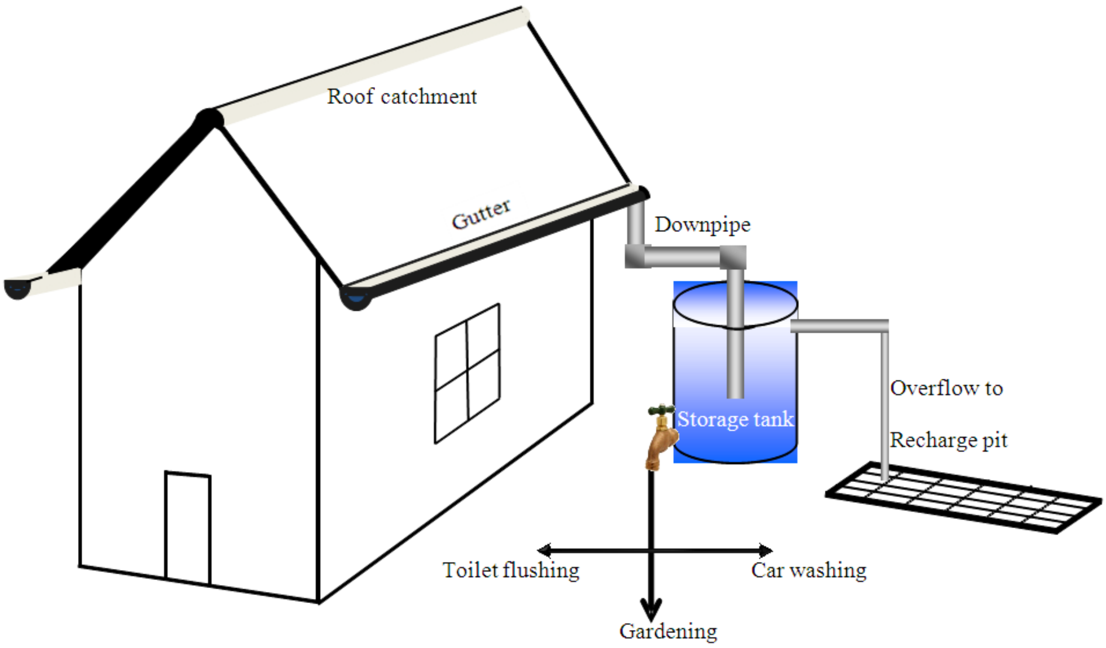



**Fig. 6.** A schematic diagram of a simple rooftop RWH system

Small dams are constructed at six locations using remote sensing satellite images and recharge wells were established for artificial recharge of groundwater. **Figure 5** shows images taken at Al Muzaira Dam, Al Hareeq Dam and Dhruma Dam in the capital city of Saudi Arabia (Riyadh). The results at Al Muzaira Dam showed that after 14 days of the rainfall event, more than 65% of the lake's water was recharged and groundwater level increased by 8.85 m during the first two days. Also, total rise in groundwater level in the observation wells was about 15 meters and water quality has been improved after the recharge (lower salinity).

In the same Project, couple of artificial ponds is also constructed at two locations and small dams are constructed to divert floodwater toward the pond and finally pipes are placed for conveying stored water to points of use. Finally, small, low-cost dams are constructed along the water washes close to old settlements and villages to store rainwater and achieve sustainable agriculture and development in the area. Findings of the project have proved water harvesting and recharge techniques cost effective in terms of the successful increase in groundwater level and improving its quality. Water harvesting and recharge techniques can be implemented to control flood and minimize its damage and stored and recharged water behind dams close to cities can be utilized in emergency situation.

Focusing at rooftop RWHM in few Arab countries only, a recent case study in Sudan has shown RWHM to provide an additional source of drinking water in a changing physical environment associated with urban population growth (Ibrahim, 2009). In Palestine, RWHM systems has shown to reduce the annual environmental impact of the in-house water usage by about 40% (Nazer *et al*., 2010) and the environmental management of RWHM was considered necessary to reduce the continuously increasing demand for fresh water (Al-Salaymeh *et al*., 2011).

These preliminary assessments of increased rain intensities coupled with extreme climate events (based on the Saudi's rainfall records) could be further combined with the old wisdom of this region for harvesting the rain and can be viewed as to demonstrate the value of rooftop RWHM (**Fig. 6**) as a local adaptation strategy to cope with the climate variability in the region.

A simple rooftop RWH system consists of its catchment area, a pre-treatment facility (simple Filtration), a storage tank, a supply facility and pipes (Han and Mun, 2008; Amin and Han, 2011). In a rooftop RWH systems, rainwater is collected from roofs and stored in cisterns to be used afterwards thus providing an alternative water resource (Baguma *et al*., 2010). The stored water by using rooftop RWH systems can be used for gardening, toilet flushing or even for car washing. If properly stored and boiled, the stored rainwater can be used for potable purposes with minimum treatment (Amin and Han, 2009a; 2009b). These small scale and decentralized rooftop RWH systemsensure the community ownership and long term sustainability through the emergence of local management system (Amin and Han, 2009c).

## 5. CONCLUSION

Saudi Arabia is an arid country and is mostly characterized by hot and dry summer with cool and slightly wet winter. The groundwater is the main source of water in Saudi Arabia which has limited renewable water resources. There are few studies investigating the future regional climate change and its impacts over Saudi Arabia, however, extreme climate events such as flood and stormy rainfall are expected to leave an impact on the climate and water management policies of Saudi Arabia. They are also expected to generate widespread response to adapt and mitigate the sufferings associated with these extremes.

Based on the Saudi's rainfall data over a period of more than three decades, authors have investigated an increasing trend in annual maximum daily rainfalls in about thirteen cities. The significance of these trends is supported further by the Durban-Watson statistical analysis. This could highlight the variability of rainfall in the whole region. An increasing annual maximum daily rainfall with a decreasing annual total rainfall was also observed for about six cities signifying the more extreme rainfall evens and resulting floods of short-durations.

A brief review of the RWHM practices in the Arab region in additon to the authors' published data for the rainfall and temperature records of the Saudi meteorological data for more than three decades for policy suggestions in the water sector. Given the factors of climate change and increasing urban population, rooftop RWHM can be a reasonable soft-path decentralized solution for water shortage and to avoid short-term flooding problems in urban areas. There is a growing need to explore this soft-path water management options in the country and both government and non-government sectors should promote the practice of RWHM at individual household's level and on community bases.

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