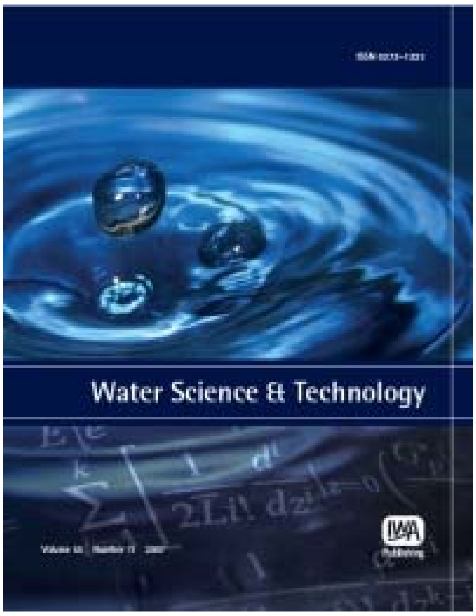
Water Science & Technology

Water Science & Technology—WST | 62.4 | 2010

# Rainwater harvesting potentials for drought mitigation in Iran

J. Tabatabaee and M. Y. Han


## ABSTRACT

In order to evaluate the potential of rainwater harvesting (RWH) for mitigating water scarcity in a semi-arid zone of the country (Mashhad-Iran), three typical RWH systems were installed and monitored. The first system consists of 5,000 $m^2$ natural ground catchment which was leveled and covered with plastic sheets allowing for maximum possible runoff generation. Surface runoff was conducted into a 500 $m^3$ ground reservoir via a series of draining ditches and an end collection channel. The water collected from a plastic covered catchment was used for irrigation of dryland wheat cultivation. According to the result of two years measurements, grain yield was almost doubled in irrigated plots when compared to conventional rainfed cultivation. In the second RWH system, runoff generated from about 2 ha asphaltic road and parking was diverted into a 1,200 $m^3$ ground reservoir. The results of 2 years measurement for reservoir inflow and outflow indicated that runoff generated during rainy season was sufficient to produce necessary water for irrigating 900 planted fruit trees during successive dry seasons. The last experiment reported here is about a 40 $m^2$ roof area which was connected to a plastic tank for runoff measurement. The conclusion was that the proposed RWH system can produce enough water for building's toilets' flashes and other sanitary purposes so that the potable water could be saved considerably. In general, the results of three rainwater harvesting experiments showed the importance of using rainwater for compensating the effect of water shortages which is repeatedly occurring due to the effect of current climate change and ever increasing water utilization for drinking and food production.


**Key words** | arid and semi arid land, dryland cultivation, rainwater harvesting, roofwater

**J. Tabatabaee** (corresponding author)
Khorasan Agriculture and Natural Resource Research Center,
Iran
E-mail: *tabatabaee_j@yahoo.com*

**M. Y. Han**
Seoul National University,
Seoul,
South Korea
E-mail: *myhan@snu.ac.kr*

## INTRODUCTION

Water shortage used to be an inherent characteristic of arid and semi arid countries such as Iran. The situation has worsened due to overexploitation of water resources and lack of proper management. The result is that many rivers are running dry and a lot of important aquifers are greatly depleted and deteriorated so that they are either not economic to extract or not safe for using (Hosseini 2005).

Following the current worldwide mission for using rainwater as a supplementary water resource (Konig 2001; Lancaster 2006; Chatfield & Coombes 2007; Krishna 2007), the Agriculture and Natural Resource Research Center of Khorasan province (N-E of Iran) carried out a number of real scale rainwater harvesting (RWH) experiments.

In spite of that the country have long history about runoff farming and water harvesting in the past centuries (Ghoddoosi 1995), present research is one of the very few and more recent attempts to evaluate the potential of rainwater utilization for different purposes.

The purpose of this paper is:

(1) To examine the effect of RWH for increasing rainfed food production,

doi: 10.2166/wst.2010.298

(2) To evaluate the potential of domestic RWH from road and roof catchments,
(3) To identify RWH systems' design parameters such as threshold rainfall (the amount of rain before the runoff starts) and runoff coefficient (rainfall/runoff ratio).

## REGIONAL INFORMATION

The study area is located in the holy city of Mashhad (N-E Iran) with 2.5 million permanent residents and 25 million yearly visitors (Figure 1). This area is characterized with low magnitude rainfalls (250 mm per year in average mainly concentrated within the wet season) and long duration dry periods (starting from May and ending on December) with no rain (Figure 2). Among the yearly 70 rainfall events, a number of exceptional high intensity rainfalls change into massive runoff and cause ground inundations and down-stream flooding. This means, in spite of the area suffering from water scarcity, a huge amount of water is being lost during the rare happening of high discharge rainfall events. According to the current prolonged drought and ever increasing water shortage within the target area, it was important to examine the effectiveness of collection and utilization of surface runoff as an alternative resource for different purposes.

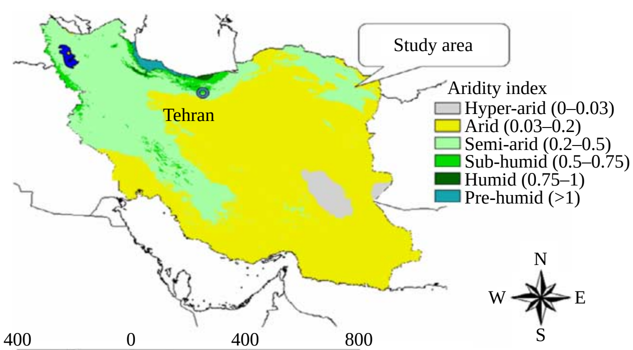


**Figure 1** | Map of Iran and location of study area (Mashad city).

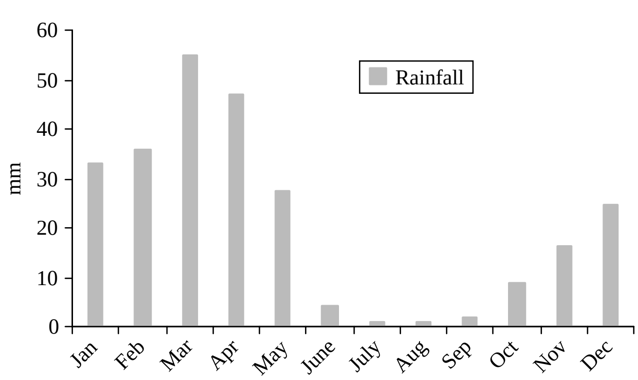


**Figure 2** | Mashhad mean rainfall distribution.

## CASE STUDY 1: RAINWATER HARVESTING FOR RAINFED AGRICULTURE

A 5,000 $m^2$ farming land was shaped as side by side ditches so that the runoff could move down from side slops and flow longitudinally towards an end collecting channel. In order to acquire maximum runoff efficiency, whole catchment was covered by plastic sheets. Runoff collected by the end channel was then discharged into the down-stream 500 $m^3$ ground storage. A recording data logger was installed at the end of collecting channel for runoff and rainfall measurements.

The experimental farmland located next to the runoff catchment was divided into 8 plots from which four plots were irrigated using RWH system and the rest four replications were accounted as control without irrigation (Figure 3).

### Wheat cultivation using rainwater irrigation

Experimental farming started on 2005 with planting a commercial wheat seed after first rainfall on Nov. 2005. Rainwater collected during wet season was conducted to the farm land (via an installed pressurized systems) during critical stages of wheat growing periods. During the first year of study a total of 105 mm rainwater were allocated for plant growth during two critical growing periods (35% of required water in excess of natural rainfall). Compared to the conventional dryland farming which was undertaken in the nearby control plots, grain yield increased by 70% (see Figure 4 and Table 1).

Second trial for supplementary irrigation practice was conducted during next year (2006–2007). It was observed that an equivalent of 150 mm runoff water (from 420 mm crop water requirement) was produced from RWH system and fed to crop during 3 critical growing stages (Figure 5).

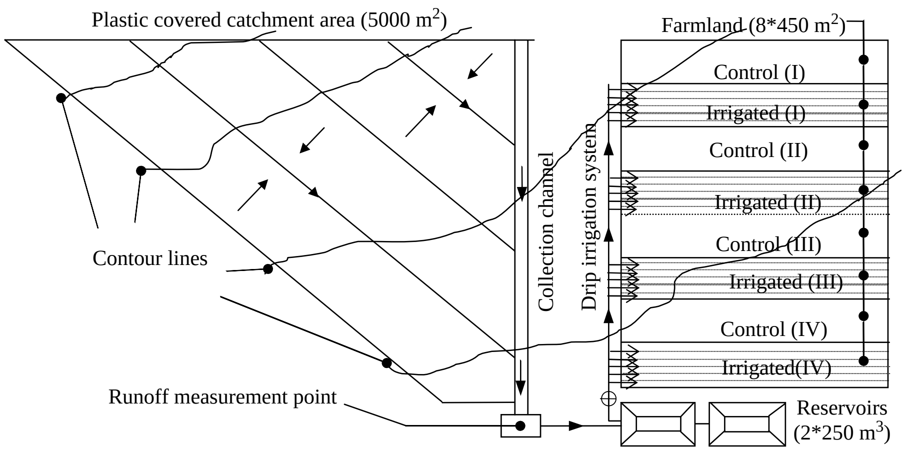


**Figure 3** | Schematic diagram of demonstration RWH system.

Compared to the control dryland farming, wheat grain yield increased in the second year by 87% (Table 1). Such a production growth is considered very satisfactory since it is beyond the normal production rate in the neighboring areas and it is also very encouraging because dryland wheat cultivation is very competitive business in arid and semi arid region of the country.

Comparing the distribution of rainfall and crop water requirement (ET) shown in Figures (4) and (5), one can also realize the impotance of rainwater storage from wet season (Dec. to May) for the subsequent dry period.

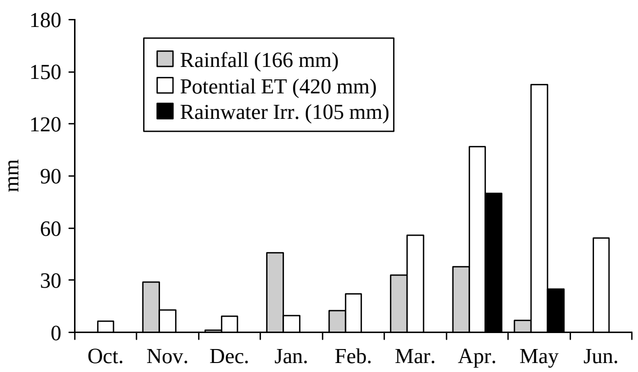


**Figure 4** | Rainfall, ET and Rainwater Irr. during 2005–2006.

**Table 1** | RWH efficiency and response of grain yield

| Year | Nat. rainfall (mm) | RWH (mm) | RWH/ET (%) | Yield (Control) (kg/ha) | Yield (Irrigated) (kg/ha) | Yield response (%) |
|---|---|---|---|---|---|---|
| 2005–2006 | 166 | 105 | 25 | 975 | 1,651 | 70 |
| 2006–2007 | 280 | 150 | 36 | 744 | 1,394 | 87 |

## Discussion

Following the installation of project's components, rainwater was collected and used for irrigation of wheat cultivation. Grain yield was compared with conventional dryland production during two successive years. The results give indication for how to confront two important dryland problems of the rainfall shortage and the mismatch of rainy season with plant water requirement. The results presented here are in agreement with others in the fact that if the minimum water required for critical time of crop growing period can be harvested from preceding rainfalls, the grain yield can be increased considerably (Oweis *et al.* 1999).

## CASE STUDY 2: RWH FOR URBAN GREEN LAND

In the next RWH pilot project, runoff generated from 19,000 $m^2$ asphaltic access roads within the Center for

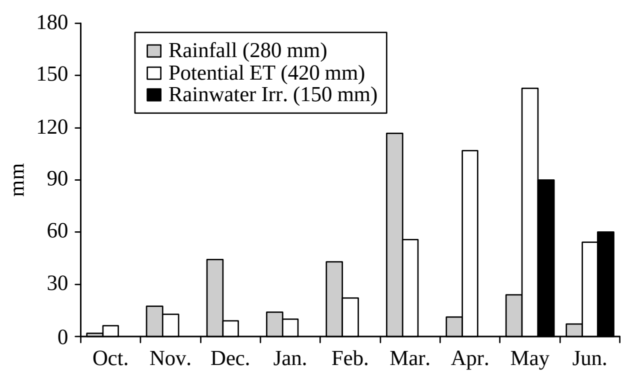


**Figure 5** | Rainfall, ET and Rainwater Irr. during 2006–2007.

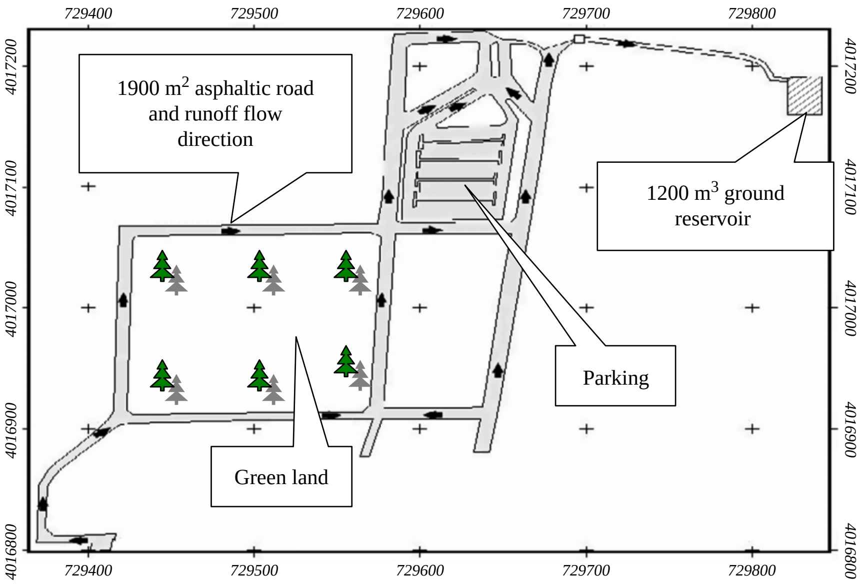


**Figure 6** | Layout of the RWH system for collecting runoff from road surface.

Agricultural Research and Education, was conducted into a 1,200 $m^3$ ground reservoir. Harvested rainwater was then used for irrigation of nine hundreds of drought resistant trees which were cultivated along the road sides. Rainfall intensity, reservoir inflow (runoff) and outflow (demand) were measured simultaneously using installed recording apparatus (Figure 6).

A total of 99 rainfall events have occurred during 18 months study period (15-April-2008 until 16-Sep.-2009). A volume of about 1,736 $m^3$ runoff generated from a total of 227 mm rainfall were collected during rainy seasons and used by 34 times irrigation during subsequent dry seasons. Figure (7) shows the result of in situ measurements for daily rainfall and corresponding runoff values. It can be seen from the results that the accumulated runoff distribution curve (dotted line) changes sharply in case of rainfalls with magnitudes of higher than about 2.5 mm. In an attempt for more exact determination of the threshold rainfall and runoff coefficient, a linear relationship is obtained by plotting the rainfalls versus runoff values (Figure 8). Some discrepancies can be realized in the results which are likely due to variations in rainfall duration and intensity as well as antecedent moisture and temperature. It can be estimated from the results that threshold rainfall and runoff coefficient are about 2.5 mm and 50% respectively.

## Discussion

- The result of rainfall measurements during the project study is in agreement with the long term distribution shown in Figure (2). It is indicating that the water shortage in in the study region is being intensified with mismatch of rainy season and critical periods of crop water requirement.
- Rainfall-runoff relationship indicates an average runoff coefficient of about 50% and a threshold rainfall of about 2.5 mm. With regards to the rainfall data, it was also observed that 71 events out of total 99 recorded rainfalls (with sum of 51 mm in magnitude) were less than 2.5 mm

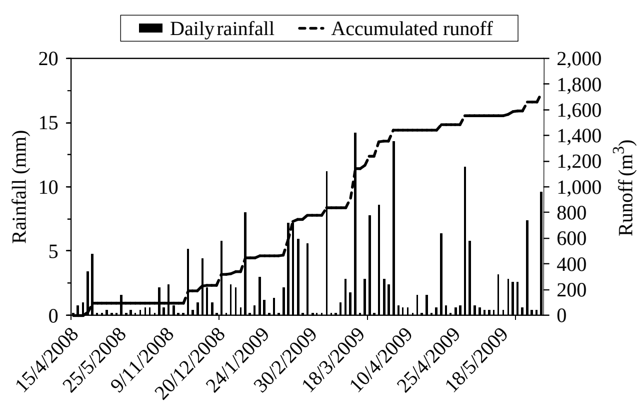


**Figure 7** | Rainfall distribution and acumulated runoff.

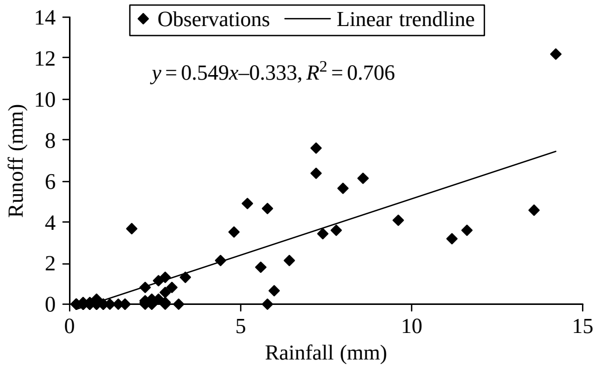


**Figure 8** | Rainfall-runoff relationship.

in height and have not had any runoff. Therefore, taking into account the loss of 45 mm of the remaining 18 events, the total losses due to rainfall threshold would become 96 mm.

- With regard to catchment area, the runoff height equivalent to the total harvested runoff value would be equal to (1,736 $m^3$/1,900 $m^2$) 91.4 mm. It means that the efficiency of the system has been equal to (91.4 mm/227 mm) 40% in general.
- A combination of rainwater harvesting methods and pressurized irrigation system along with selecting drought resistance species gave hope of finding some ways to cope with current drought condition and extreme dryness.

## CASE STUDY 3: RWH FROM THE ROOF FOR DOMESTIC USE

The next rainwater harvesting system was consisted of a 40 $m^2$ flat roof covered with bituminous fiberglass and a downpipe connected to a 3 $m^3$ plastic tank (Figure 9). It was planned to assess the feasibility of using rainwater for indoor sanitary consumption in the nearby buildings. Daily rainfalls were measured during two years (2008–2009) using a rain guage installed at the same place where as runoff was measured by observing water level in the tank. A total of 37 observations were recorded during wet season. After each reading, tank was emptied to be prepared for next event. Mean rainfall height during study period has been 113.7 mm and 257.3 mm for years 2008 and 2009 respectively.

Figure 10 indicates rainfall and runoff relation making use of linear correlation. Generalization has been made by using the proposed relation (Figure 10) for estimating the potential runoff from the past 18 years daily rainfalls recorded by Mashhad meteorological center. The result indicates that yearly average of about 16,000 l of rainfall can be harvested from every similar catchment with the same size (40 $m^2$) and isolation (fiberglass). It can be concluded that there is a great potential for using rainwater for indoor consumptions.

## Discussion

- Roofing material with black color (absorbing solar energy), heating systems used within the building and surface depressions could have been some of the major causes for runoff losses particularly during low magnitude rainfalls.
- Compare to the last experiment (case study two), the current results show lower threshold rainfall and higher runoff coefficient. The reason could be mainly due to size

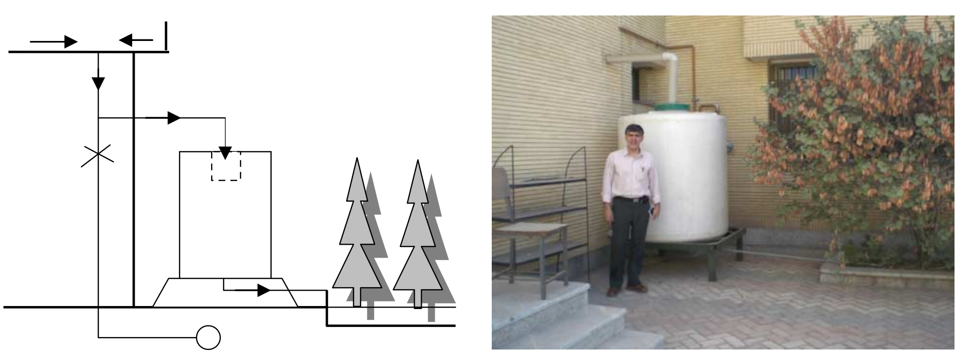

**Figure 9** | Roofwater downpipe and collection tank (First author is standing next to the raintank).

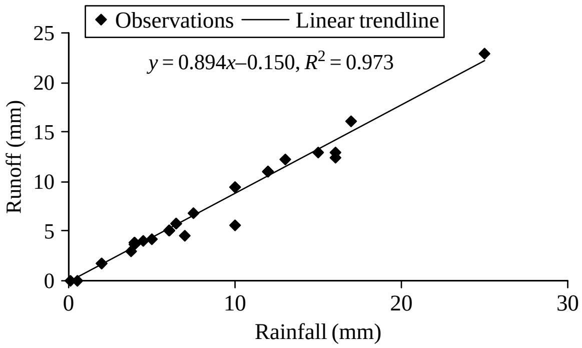


**Figure 10** | Rainfall-runoff relationship obtained from measurement and linear fitness.

effect since other conditions (such as topography and climate) have been almost the same (Oweis *et al.* 1999).
- Generalizing the results for the whole available surfaces indicated that a considerable water saving would be possible by applying rainwater harvesting method.
- Characteristics of drought prone area such as high variation in annual rainfall is clearly represented in the abovementioned observations.

## CONCLUSION

Water shortage and consequent decrease of food production has seriously endangered people living in arid part of the world (including Iranians). This problem has been partially addressed by the concept of rainwater management which implies a decentralized and participatory approach for rainwater utilization, taking advantage of vastly available unused land in targeted areas. Crop's required water in excess of natural rain can be harvested from neighboring area and being reserved for following dry period or before the next rain occurs. This practice can evolve conventional dryland farming by increasing crop's productivity, which may not virtually be considered beneficial at all.

The results of three large scale field experiments using different catchment systems indicate that RWH systems can be considered as an efficient tools for drought mitigation measures and water shortage management in arid and semi arid regions of Iran and the world.

## ACKNOWLEDGEMENTS

The authors greatly appreciate all support received from Khorasan Agriculture and Natural Resources Research Center and Department of Soil Conservation and Watershed Management directed by prof. H. Tavakoli and prof. A. A. Abbasi respectively.

## REFERENCES

Chatfield, R. C. & Coombes, P. 2007 Urban rainwater harvesting–analysis of a decentralized approach for meeting water demand in urban cities. *Proceedings of the American Rainwater Catchment System Association Conference*, pp. 18–28.

Ghoddoosi, J. 1995 An overlook to the development and use of rainwater harvesting systems in Iran. *Proceedings of 7th Int. Conf. on Rainwater Catchment Systems*. Beijing, China, (Vol. 2), pp. 26–36.

Hossaini, S. M. 2005 Status of water resources in Khorasan province. *Integrated Water Resources Management Workshop, Khorasan Water Association with collaboration of Unesco*. 21–22 Dec. Mashhad, Iran.

Konig, K. W. 2001 *The Rainwater Technology Handbook*. Wilo-Brain Publisher, Rainharvesting in building.

Krishna, H. J. 2007 Rainwater harvesting potential and water quality guidelines in Texas. *Proceedings of the American Rainwater Catchment System Association Conference*, pp. 76–85.

Lancaster, B. 2006 *Rainwater Harvesting for Drylands, Vol. 1: Guiding principles to welcome rain into your life and landscape*. Rainsource Press.

Oweis, J., Hachum, T. A. & Kijne, J. 1999 Water harvesting and supplementary irrigation for improved water use efficiency in dry areas. *SWIM Paper 7. International*.