Methods of Rain Water harvesting and its effects on food, economy and environment

Hamed Beigi*, Samad Mohseni

Master student in watershed management, Department of Reclamation of Arid and Mountainous Regions, Faculty of Natural Resources, University of Tehran, hamedz1373@gmail.com

Master student in watershed management, Department of Reclamation of Arid and Mountainous Regions, Faculty of Natural Resources, University of Tehran, Sa.mohseni@ut.ac.ir

hamedz1373@gmail.com

Abstract

As the world population increases, the demand increases for quality drinking water. Rainwater harvesting systems (RWHS) have been accepted as a simple and eﬀ ective approach to ease the worsening of water stress. Rainwater harvesting is defined as the accumulation and deposition of rainwater for reuse on-site, rather than allowing it to run off. Many countries around the world are facing water shortages. Optimization of water usage and the conservation of water as a natural resource can help to overcome water shortage. Rainwater can be used for potable and non-potable uses. In a typical rainwater harvesting situation, rainwater is collected from an impervious surface such as the roof of a building and then stored inside a tank or cistern. Other surfaces include parking lots, roadways, driveways, and even land surfaces (once surface runoff from the land surface begins). Rainwater can be harvested and stored for many uses including landscape irrigation, potable and non-potable indoor use, and storm water management. RWH systems has been investigated using different approaches, including water balance simulation analyses and mass curve analyses , probabilistic methods and economic optimization . The main advantages of rainwater harvesting systems are conserving water resources and environment, pollution reduction, help to control flooding, and reduction of impact of weather change.

Key words: Water harvesting, Rainwater

1. Introduction

Water plays an important role in the growth and development of the agricultural sector, food security and job creation. Water scarcity and stress are reaching worryingly high levels worldwide due to the intensive exploitation and pollution of water resources. The supply of food is one of the greatest challenges faced by humankind in the 21st century [1]. Water resources are subject to severe degradation due to many factors, such as the consequences of global climate change, rapid population growth, changes in land use, agricultural and urban expansion, the increase in the demand for water from different productive sectors, the inadequate distribution of water resources, regional hydropolitical conditions, the deterioration of the quality of water due to overexploitation, rainwater scarcity, and the high rate of evaporation and aridity resulting from the increase in temperatures [2,3]. Rainwater harvesting is defined as the accumulation and deposition of rainwater for reuse on-site, rather than allowing it to run off. While this definition is basic, the practice of rainwater harvesting is greatly varied from where the rainwater is collected to how the rainwater is ultimately used. In a typical rainwater harvesting situation, rainwater is collected from an impervious surface such as the roof of a building and then stored inside a tank or cistern. Other surfaces include parking lots, roadways, driveways, and even land surfaces (once surface runoff from the land surface begins). Rainwater can be harvested and stored for many uses including landscape irrigation, potable and non-potable indoor use, and storm water management. Rainwater harvesting may be an effective supplementary water source because of its many benefits and affordable costs [4,5,6,7]. Because of their many environmental and economic advantages, rainwater harvesting (RWH) systems are currently receiving increased attention as alternative sources of drinking water, especially in semi-arid areas [8.9.10], but also in urban areas [11].

RWH systems involve three principal components: the catchment area, the collection device and the conveyance system. Rainwater is commonly collected from rooftops, courtyards or other compacted or treated surfaces before being filtered and collected in storage tanks to be used. RWHI implies harvesting, storing, and conserving rainwater (or the run-off derived from a catchment area of a reservoir) directly, in a farmed area that is generally smaller than the size of the catchment area [12,13]. The performance and design of RWH systems has been investigated using different approaches, including water balance simulation analyses and mass curve analyses [14,15,16,], probabilistic methods [17] and economic optimization. Bruins et al. [19] estimated that, in arid regions where water is the only limiting factor to the expansion of arable land, an additional 3–5% of the surface area could be farmed using run-off for irrigation. Different experiences with these types of irrigation practices have given rise to increases in crop yields and water-use efficiency in different parts of the world, and their contribution to mitigating the impacts of climate change on agriculture [18,20,21,22,].

Alteration of environment due to global weather change brings about extreme climate events such as drought and flood. Observation showed that drought and flood affected the water resources utilization for various purposes. As a result, many countries adopting strategies to conserve the available water resources including promoting the usage of rainwater harvesting technique for landscaping and agriculture.

Several studies have explored the implementation of RWH systems in response to growing water demand in Africa [23,24,25], Asia [26,27,28], USA. [17,18,19,20,21,22,23,24,25,26,27,28] and Australia [18,19,20,21,22,23,24,25,26,27,28,29].

2. Methods of Rainwater harvesting

Broadly there are two ways of harvesting rainwater, namely; surface runoff harvesting and rooftop rainwater harvesting (Figure 1, 2). Rainwater harvesting is the collection and storage of rain for reuse on-site, rather than allowing it to run off. The stored water is used for various purposes, such as gardening, irrigation, etc.

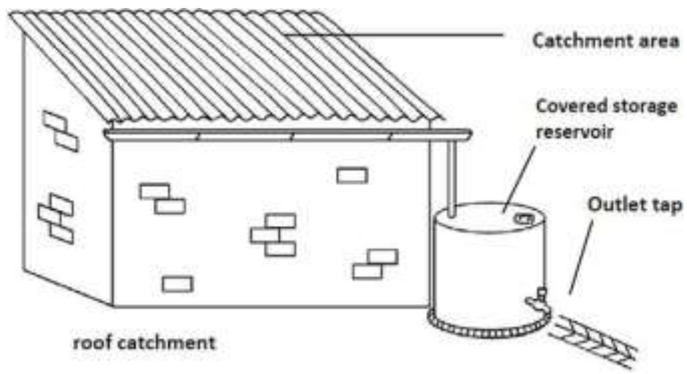

Figure 1: Rooftop catchment system (source: CTCN site).

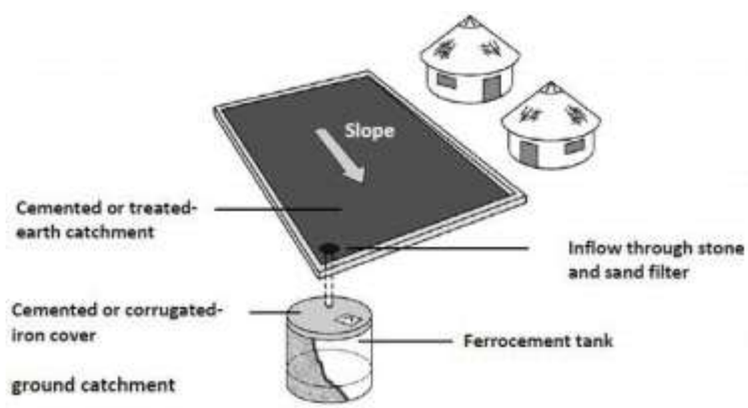

Figure 2: Ground catchment system (source: CTCN site).

3. Benefits of rain water harvesting system

- ❖ Rainwater is a comparatively clean and totally free source of water.
- ❖ Rainwater is improved for scenery plants and gardens because it is not chlorinated.
- ❖ It can supplement other sources of water supply such as groundwater or municipal water connections.
- ❖ It lower the water supply cost.
- ❖ It can provide an excellent back-up source of water for emergencies.

- ❖ It is socially acceptable and environmentally responsible.
- ❖ It uses simple technologies that are inexpensive and easy to maintain.
- ❖ It Reduced flood flows and topsoil loss.
- ❖ It is free; the only cost is for collection and use.
- ❖ It reduces the contamination of surface water with sediments, fertilizers and pesticides from rainwater run-off resulting in cleaner lakes, rivers, oceans and other receivers of storm water.
- ❖ It is used in those areas which face insufficient water resources.
- ❖ It is good for laundry use as rainwater is soft and lowers the need for detergents.
- ❖ It can be used to recharge groundwater.
- ❖ It minimizes the runoff which blocks the storm water drains.

4. Rain Water Harvesting Studies

In a study in Pakistan the rainwater harvesting project improved people situations. Figure(3) shows how it works.

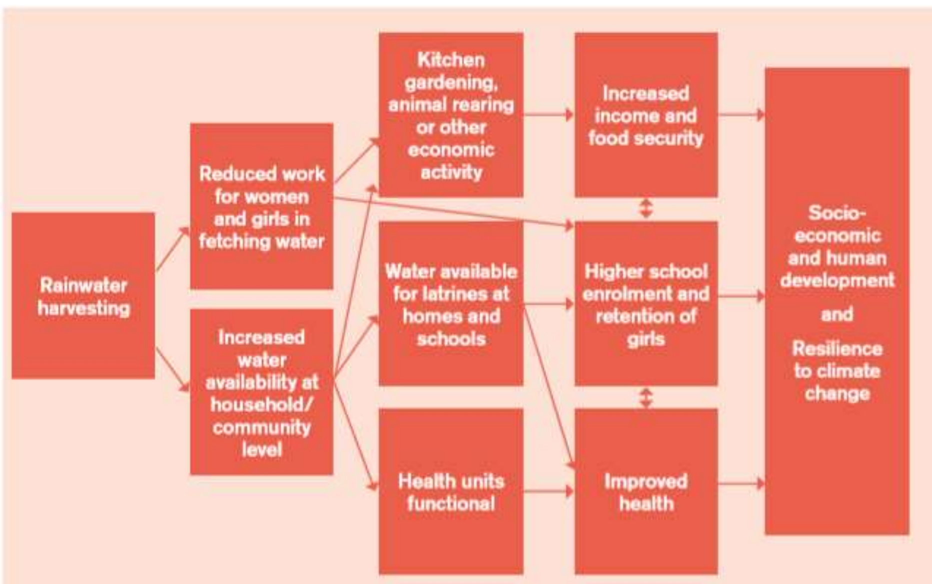

Figure 3: rainwater harvesting and the impacts in Pakistan

The project in Pakistan had two immediate impacts: it increased the amount of water available per household by providing storage, and greatly reduced the workload of women and girls. this freed up a significant amount of time and provided water for other activities, allowing women to focus on kitchen gardening and animal rearing. By increasing water storage and availability at home, the project also addressed climate resilience, reducing the impact of rainfall variability and springs drying up. By making additional water available to households, the RWH project has contributed to an increase in agriculture and livestock output. More importantly, women have more free time and can use it productively to rear animals and increase kitchen gardening. Livestock holdings increased on both project sites, but was more pronounced in Bagh, with an average increase of 1.2 cattle per household, compared to an average increase of 0.6 in Abbott abad,Table[1]. this can be attributed to the existence of alternative incomegenerating opportunities such as tourism in the latter, and the easy and timely availability of dairy products and meat in local markets. Savings from growing and producing food for the household contributes significantly to the family income.

Socio-economic indicators can be further combined with livelihood and food security indicators to monetise savings from food production and diversification, using the health and education indicators defined above. Table [1] provides a summary of socio-economic indicators, with monetised values. they show significant increases in average food production and savings in medical costs per household between the treatment and control groups.

Table 1: Summary of results

VARIABLES	INDICATORS	BAGH	ABBOTTABAD
		(AVERAGE PER TREATMENT HOUSEHOLD)	
Increased water availability	Water usage (litres/day)	92	15
Reduced workload fetching water	Reduction in number of minutes spent fetching water each day	162	60
School-age girls fetching water	Reduction in number of school-age girls fetching water	1.6	0.7
Kitchen gardening	Households with kitchen gardens (%)	27	0
Livestock holding	Increase in number of cattle owned	1.2	0.6
Sanitation	Reduction in open defecation (%)	53	41
Sanitation	Increase in use of functional toilet (%)	20	14
Hygiene	Increase in frequency of showers per week	1	0.7
Health improvement	Decrease in frequency of injury or illness among women from fetching water each month	3	3

RWH programme has brought socio-economic and environmental benefits for individuals and communities, and for women in particular. It has proven to increase water availability and, with more erratic rainfall patterns predicted, it should reduce the impact of climate change. At the same time, the project increased productivity in agriculture and livestock, significantly improving food security and nutritional status. It also had positive impacts on women's wellbeing in terms of improved health, reduced workload and empowerment, enabling them to supplement their incomes and improve their food security.

In West Africa, rainwater harvesting technologies can be classified into three major categories as shown in Table 2; detailed descriptions of these and many other technologies in Africa have been published [30,31,32].

Table 2: rainwater harvesting technologies in West Africa

A. Non-indigenous rainwater harvesting technologies	B. Traditional micro-catchment (runoff harvesting technologies)*	C. Macro-catchment runoff farming technologies
1. Plowing	1. Rock-bunds/stone rows	1. Bouli[1]
2. Ridge tillage	2. Contour earthen bunds	2. Farmers' micro-reservoir
3. Hilling	3. *Zai/tassa*	3. Micro-sand dams
4. Soil scarifying	4. Straw mulching	
	5. Half-moon[2]	

* Zai/tassa (water pocket) is a traditional practice developed by Sahelian farmers and consists of creating holes about 0.2-0.40 meters (m) wide and 0.10-0.25 m deep. Two handfuls of organic amendment such as cropresidues, manure or their composted form are then placed in the pits.
1 Bouli, the *"bouli"* reservoir is an artificial pool dug at the foot or midway up a slope at a point where there is convergence of runoff and water collected lasts for 2-3 months after the rains and is mainly used for livestock and to irrigate market garden crops.
2 Half-moon, the technique consists of making a hole in the form of a half-moon, and placing the removed earth on the downhill side.

A study by Ngigia (2005) in the Laikipia district, Kenya showed that improved farm ponds provide one of the feasible options of reducing the impacts of water deficit that affect agricultural productivity in semi-arid environments in SubSaharan Africa. The field evaluation revealed that on-farm RWH systems are common in the study area with sizes ranging from 30 to 100 m3 and catchment areas varying from 0.3 to 2 ha. The hydrological evaluation of the farm ponds revealed that one of the challenges was how to reduce the seepage and evaporation water losses. He reported significant water losses through seepage and evaporation, which accounted on average for 30–50% of the stored runoff. The high losses are one of the factors that affect the adoption and up-scaling of on-farm water storage systems. If seepage loss is reduced with lining material and if RWH is combined with drip irrigation on-farm storage systems can be economically viable and farmers are able to recover the full investment costs within 4 years. soil fertility parameters under Zaï treatment showed a systematic improvement after 3 and 5 years. For example, organic matter content increased from 1 to 1.4% and nitrogen increased from 0.05 to 0.8%. Soil structure also improved considerably with an increase in its clay content and a decrease in the sand fraction. This is not surprising since pits (Zaï) are generally dug on barren, crusted soils which do not allow water infiltration.

Socioeconomic Impact of Rainwater Harvesting Technologies

In villages of Ranawa (Burkina Faso), the number of poor families decreased by 50% between 1980 and 2001 [30]. This was largely due to the wide range of RWH and SWC activities undertaken in these villages since 1985, which led to the progressive rehabilitation of about 600 ha of degraded land which became available for food production. The environmental and socioeconomic situation in the village was critical in the early 1980s. Due to recurrent droughts and food shortages, 49 families were reported to have left the village between 1970 and 1980 (25% of all families) and settled in neighboring Cote d'Ivoire or in more fertile and higher rainfall parts of Burkina Faso. However, through the wide use of RWH and SWC technologies, more land is now cultivated and grain yields have significantly increased. This has led to a significant improvement in household food security and a noticeable number of people have come back to cultivate their previously abandoned land.

In Iran The average annual water consumption is approximately 8% higher than the total sustainable water supply. The latest studies on the drinkable water situation in Iran show that under the current status of water, the population under water stress has reached up to 80% of the total population of the country(33,34). This study used a compensatory method, integrated determination of objective criteria weights (IDOCRIW), which was introduced by Zavadskas and Podvezko in 2016 [35]. In this method, attributes (criteria) are independent, and qualitative attributes can be converted into quantities. This method consists of two widely used methods: entropy and CILOS. In addition, the most commonly used TOPSIS method is applied to determine the rank order of alternative weights.

Table 3: Diﬀ erent water-saving methods and criteria values (decision matrix).

	APWS [1]	*AAS* [2]	Initial Cost [3]	BCR [4]	Supported by [5] Government	Social Benefits [6]	Environmental [7] Benefits
RWH-A	*	*	*	*	3	5	3
RWH-B	*	*	*	*	3	5	5
GWR	47.1	$18.37	$1040	—	4	3	4
WCRE	79.4	$30.98	$260	—	5	2	2

[1,2] *APWS* obtained from simulation method for RWHS scenarios and for others by from different guidelines such as gray-water reuse guide for non-drinking use (in Persian), prepared by "Road, Housing & Urban Development Research Center" of Iran downloaded from http://www.WaterCM.ir and local market data. *AAS*, average annual saving ($/year), is the *APWS* ($m^3$/year) times the water price ($/$m^3$). [3] Investment or initial cost was obtained in the design stage, including all components of a domestic RWHS. To determine the price of all components of the system, several price lists for mechanical equipment and installation, rural drinking water, and price quotes from several water supply stores, including polyethylene tanks, pumps, and pipes, were used. [4] Benefit cost ratio calculated in the economic analysis section for all stations, all scenarios and all schemes and comparing the average. [5,6,7] Socio-environmental criteria ranked by a Likert scale according to expert opinion and domestic guidelines and reports. * Results from simulation and LCCA section.

Urban water stress has severely challenged the development of human society, particularly in developing countries such as Iran. Potable water-saving methods, e.g., RWHSs, GWR, and WCRE, should be wisely adopted in Iran to address such a water crisis. In this paper, the spatial-temporal complexity of rainfall, the economic performance, and the social and environmental aspects of water- saving methods have been incorporated forlarge-scale applications. This study has demonstrated the utility of GIS-simulation-based DSS in Guilan Province. The hydraulic performance of RWHSs was obtained and further mapped. The LCCA was performed to compare the USC of all the water-saving methods. Apart from economic factors, the MCDM also adopted social and environmental factors to prioritize water-saving methods in large-scale applications. Compared with the traditional generalized method, the sensitivity analysis has identified that the information value of DSS has been enhanced. Such a DSS also provides a straightforward and simple approach to understanding the water-saving scheme and therefore off ers the potential for public participation. For further research, the climate change issue can be added in the hydraulic simulation. The web-based interface of this DSS can be further refined to be more end-user friendly before opening it to the public. Consequently, this DSS is a useful tool and helpful on a large-scale water-saving scheme and can be used to ease the worsening of water stress.

5. Conclusions

Demand on water resources witness a substantial increase due to development, population increase, and global weather change. Efficient management of water resources and education about judicious utilisation of water resources along with measures of harnessing, recharging and maintaining the quality of water and water bodies has to be taken up on war footing. Rainwater harvesting can also be used for landscaping and agriculture. Plants and the grass used for various types of landscaping can be irrigated by using rainwater harvesting. The rainwater used for irrigating plants are salt free and this will contribute to creates a healthily environment for the root to grow. Also Rainwater harvesting can reduce the water pollution and conserve the environment by controlling the erosion and reduce the sediment concentration in the storm runoff.

References

[1] Hasan, M.K.; Desiere, S.; D'Haese, M.; Kumar, L. Impact of climate-smart agriculture adoption on the food security of coastal farmers in Bangladesh. Food Sec. 2018, 10, 1073.

[2] Liu, J.; Wang, Y.; Yu, Z.; Cao, X.; Tian, L.; Sun, S.; Wu, P. A comprehensive analysis of blue water scarcity from the production, consumption, and water transfer perspectives. Ecol. Indic. 2017, 72, 870–880.

[3] Fiaz, S.; Noor, M.A.; Aldosri, F.A. Achieving food security in the Kingdom of Saudi Arabia through innovation: Potential role of agricultural extensión. J. Saudi Soc. Agric. Sci. 2018, 17, 365–375.

[4] Imteaz M. A., Ahsan A., Naser J. & Rahman A. 2011 Reliability analysis of rainwater tanks in Melbourne using daily water balance model. Resour. Conserv. Recycl. 56, 80–86.

[5] Imteaz M. A., Rahman A. & Ahsan A. 2012 Reliability analysis of rainwater tanks: a comparison between South-East and Central Melbourne. Resour. Conserv. Recycl. 66, 1–7.

[6] Cook S., Sharma A. K. & Gurung T. R. 2014 Evaluation of alternative water sources for commercial buildings: a case study in Brisbane, Australia. Resour. Conserv. Recycl. 89, 86–93.

[7] Liuzzo L., Notaro V. & Freni G. 2016 A reliability analysis of a rainfall harvesting system in southern Italy. Water 8, 18.

[8] Pandey, D.N.; Gupta, A.K.; Anderson, D.M. Rainwater harvesting as an adaptation to climate change. Curr. Sci. 2003, 85, 46–59.

[9] AbdelKhaleq, R.; Ahmed, A. Rainwater harvesting in ancient civilizations in Jordan. Water Sci. Technol. Water Suppl. 2007, 7, 85–93.

[10] Kahinda, J.M.M.; Taigbenu, A.E.; Boroto, J.R. Domestic rainwater harvesting to improve water supply in rural South Africa. Phys. Chem. Earth 2007, 32, 1050–1057.

[11] Farreny, R.; Gabarrell, X.; Rieradevall, J. Cost-efficiency of rainwater harvesting strategies in dense Mediterranean neighbourhoods. Resour. Conserv. Recycl. 2011, 55, 686–694.

[12] Kiggundu, N.; Wanyama, J.; Mfitumukiza, D.; Twinomuhangi, R.; Barasa, B.; Katimbo, A.; Kyazze, F.B. Rainwater harvesting knowledge and practice for agricultural production in a changing climate: A review from Uganda's perspective. Agric. Eng. Int. 2018, 20, 19–36.

[13] Boers, T.M.; Ben-Asher, J. A review of rainwater harvesting. Agric. Water Manag. 1982, 5, 145–158.

[14] Villarreal, E.L.; Dixon, A. Analysis of a rainwater collection system for domestic water supply in Ringdansen, Norrköping, Sweden. Build. Environ. 2005, 40, 1174–1184.

[15] Ghisi, E.; Bressan, D.L.; Martini, M. Rainwater tank capacity and potential for potable water savings by using rainwater in the residential sector of southeastern Brazil. Build. Environ. 2007, 42, 1654–1666.

[16] Panigrahi, B.; Panda, S.N.; Mal, B.C. Rainwater conservation and recycling by optimal size on-farm reservoir. Resour. Conserv. Recycl. 2007, 50, 459–474.

[17] Guo, Y.; Baetz, B.W. Sizing of rainwater storage units for green building applications. J. Hydrol. Eng. 2007, 12, 197–205.

[18] Bafdal, N.; Dwiratna, S. Water Harvesting System as an Alternative Appropriate Technology to Supply Irrigation on Red Oval Cherry Tomato Production. Int. J. Adv. Sci. Eng. Inf. Technol. 2018, 8, 561–566.

[19] Bruins, H.J.; Evenari, M.; Nessler, U. Rainwater-harvesting agriculture for food production in arid zones: The challenge of the African famine. Appl. Geogra. 1986, 6, 13–32.

[20] Pandey, D.N.; Gupta, A.K.; Anderson, D.M. Rainwater harvesting as an adaptation to climate change. Curr. Sci. 2003, 85, 46–59.

[21] Yin, M.; Li, Y.; Xu, Y.; Zhou, C. Effects of mulches on water use in a winter wheat/summer maize rotation system in Loess Plateau, China. J. Arid Land 2018, 10, 277.

[22] Saoub, H.M.; Al-Tabini, R.; Al-Khalidi, K.; Ayad, J.Y. Effect of Three Water Harvesting Techniques on Forage Shrub and Natural Vegetation in the Badia of Jordan. Int. J. Bot. 2011, 7, 230–236.

[23] Kahinda, J.M.M.; Taigbenu, A.E.; Boroto, J.R. Domestic rainwater harvesting to improve water supply in rural South Africa. Phys. Chem. Earth 2007, 32, 1050–1057.

[24] Ahiablame, L.; Engel, B.; Venort, T. Improving water supply systems for domestic uses in Urban Togo: The case of a suburb in Lomé. Water 2012, 4, 123–134.

[25] Woltersdorf, L.; Liehr, S.; Döll, P. Rainwater harvesting for small-holder horticulture in Namibia: Design of garden variants and assessment of climate change impacts and adaptation. Water 2015, 7, 1402–1421.

[26] Ahiablame, L.; Engel, B.; Venort, T. Improving water supply systems for domestic uses in Urban Togo: The case of a suburb in Lomé. Water 2012, 4, 123–134.

[27] Woltersdorf, L.; Liehr, S.; Döll, P. Rainwater harvesting for small-holder horticulture in Namibia: Design of garden variants and assessment of climate change impacts and adaptation. Water 2015, 7, 1402–1421.

[28] Hanson, L.S.; Vogel, R.M.; Kirshen, P.; Shanahan, P.; Starrett, S. Generalized Storage-Reliability-Yield Equations for Rainwater Harvesting Systems. In Proceedings of the world environmental and water Resources Congress, Kansas City, MO, USA, 17–21 May 2009.

[29] Hajani, E.; Rahman, A. Reliability and cost analysis of a rainwater harvesting system in peri-urban regions of Greater Sydney, Australia. Water 2014, 6, 945–960.

[30] Ngigi, S. 2003. Rainwater harvesting for improved food security: promising technologies in the Greater Horn of Africa. Greater Horn of Africa Rainwater Partnership (GHARP) and Kenya Rainwater Association (KRA), Nairobi, Kenya

[31] FAO. 2001. Water harvesting in Western and Central Africa. Proceedings of a regional workshop held in Niamey, October, 1999. 117 p. Food and Agriculture Organization, Accra, Ghana

[32] Drechsel, P.; Olaleye, A. O.; Adeoti, A.; Thiombiano, L.; Barry, B.; Vohland, K. 2005. Adoption Driver and Constraints of Resource Conservation Technologies in sub-Saharan Africa. 21 pp. Available at http://www.iwmi.cgiar.org/africa/ West/pdf/AdoptionConstraints-Overview.pdf (full version).

[33] Mohsen, B. Mesgaran, Pooya Azadi, A National Adaptation Plan for Water Scarcity in Iran, Working Paper 6, Stanford Iran 2040 Project; Stanford university: Stanford, CA, USA, August 2018.

[34] ExamintheLatestStateofDrinkingWaterinDiﬀ erentAspects. 2018. Availableonline: http://www.WaterCM. ir (accessed on 19 September 2019). (In Persian).

[35] Zavadskas, E.K.; Podvezko, V. Integrated determination of objective criteria weights in MCDM. Int. J. Inf. Technol. Decis. Mak. 2016, 15, 267–283.