Karaelmas Fen ve Mühendislik Dergisi
Journal home page: http://fbd.beun.edu.tr

Research Article

Rainwater Harvesting Analysis for Bülent Ecevit University Central Campus

Bülent Ecevit Üniversitesi Merkez Kampüsü Yağmur Suyu Toplama Sistemi Analizi

İsmail Hakkı Özölçer

Bülent Ecevit University, Civil Engineering Department, Zonguldak, Turkey

Abstract

Fresh water resources are under the risk of exhausting and contamination by increasing population and industrial activities in 20th century. Rainwater harvesting is, one of the best ways to reach clean water for many undeveloped countries, also sustainable, economical and environment friendly water resource for developed countries. Rainwater harvesting systems are usually an alternative approach for a house or a single building due to limited storage volume. Bülent Ecevit University (BEU) Farabi Campus is located in the center of Zonguldak city, connected to the Zonguldak Municipal water distribution network. Central campus total water consumption is about 22,500 m^3 water and the cost is more than 194,000 TL per a year. Two different rainwater harvesting projects are proposed to supply water to BEU Central Campus water distribution network which decrease the discharged water from the municipal water network. The alternative projects are evaluated and it is proved that the connected rainwater collection and distribution system has better performance than the separated system.

Keywords: Rainwater harvesting, Water consumption profile, Economic analysis, Simulation analysis

Öz

20. yüzyılda, Temiz su kaynakları nüfus artışı ve endüstriyel aktiviteler dolayısı ile tükenme ve kirlenme riski altında bulunmaktadır. Yağmursuyu toplama, çoğu gelişen ülkeler için sürdürülebilir, ekonomik ve çevre dostu su kaynağı olması yönünden en iyi temiz suya ulaşma yollarından birisidir. Yağmur suyu toplama genellikle sistemleri evler ve binalar için belirli hacimde bir su depolama açısından alternative yöntemlerdir. Bülent Ecevit Üniversitesi merkez kampüsü Zonguldak şehir merkezindedir ve Zonguldak Belediyesi su şebekesine bağlıdır. Merkez kamoüs toplam su tüketimi yıllık yaklaşık 22,500 m^3 ve fiyatı 194,000 TL'dir. Belediye den alınan su debisinde azalma yapacak iki adet farklı yağmursuyu toplama projesi sunulmuştur. Alternatif projeler değerlendirilmiş ve birleşik yağmursuyu toplam sisteminin ayrık sisteme göre daha iyi performans gösterdiği ortaya konulmuştur.

Anahtar Kelimeler: Yağmursuyu toplama, Su harcama profile, Ekonomik analiz, Benzeşim analizi

1. Introduction

At the second half of 20th century with increased population and urbanization large-scale centralized cities are became more common. Consequently local drinking water resources vulnerable to shortages and water quality deterioration. Moreover climate projections provide abundant evidence that freshwater resources are strongly impacted by climate change. Specifically, it seems that current water management practices may not be robust enough to cope with the impacts of climate change (Bates et al. 2008). Although it is an old water supply method, attention is now focusing on rainwater harvesting (RWH) systems as supplementary water sources with multi-purpose functions (Villarreal et al. 2005, Tam et al. 2010, Domènech and Sauri 2011, Patel et al. 2014).

With development of modern 'conventional' water supply systems in the first half of 20th century, many traditional water sources went out of favor. This was the case with rainwater harvesting technologies which came to be considered only as an option of last resort. While the exploitation of rainwater was considered appropriate in certain extreme situations such as on coral islands or at remote farms for which reticulated supplies were uneconomic, little serious consideration was given to the more general use of the technology. Archeological studies exhibit that rain water harvesting have been using for 4000 years in Jordan (Basinger et al. 2010) for agricultural irrigations and ancient Greeks uses cisterns store rainwater for dry seasons. United Nations have been promoted rainwater harvesting in

---

*Corresponding Author: ozolcer@hotmail.com

Received / Geliş tarihi : 01.02.2016
Accepted / Kabul tarihi : 24.03.2016

developing counties for increase human well-being (UNEP 2009). Rainwater harvesting have primary effects such as ending poverty and hunger, satisfying gender equality, increasing children health, environmental sustainability and also secondary effects on supplying universal education, increasing maternal health and combat HIV/AIDS (UNEP 2009).

RWH applications can be seen all around the world from the poorest to the richest countries, from the driest to the rainiest regions. The scales of the projects are also in varying from single house to an airport. Thousands of roof catchment and tank systems have been constructed at a number of primary schools, health clinics and government houses throughout Botswana by the Ministry of Local Government. 2,183,000 rainwater tanks had been built with a total capacity of 73.1 million m^3 in Gansu Province of China, supplying drinking water for 1.97 million people and supplementary irrigation for 236,400 ha of land. Rainwater utilization systems were introduced in Berlin Germany as part of a large scale urban re-development, to control urban flooding, save city water and create a better micro climate. The 8,400 m^2 roof top of Tokyo Ryogoku Kokugikan Sumo-wrestling Arena is the catchment surface of the rainwater utilization system. Collected rainwater is drained into a 1,000 m^3 underground storage tank and used for toilet flushing and air conditioning.

RWH systems are economically examined with different aspects such as storage tank volume, rainwater usage purpose and annual rainfall. Economy of rainwater using in primary domestic use in houses is studied by several authors (Worm and Van 2006). Some of the researches carried out so far, identifying their location, annual rainfall, the approach of the research and two economic parameters is summarized in Table 1. Since wide catchment areas and available space for system most research is based on the single-family building. There are a few research bases on multi-stored building. Under the effect of given interest rates many study gives significant discount periods (Farreny et al. 2011).

On the other hand there are many other productive applications of RWH systems on public facilities and industrial plants. Two large underground rainwater tanks are located in Swinburne University of Technology campus in Melbourne, Australia (Mitchell et al. 2005). The main purpose of these two tanks in the university campus is to capture storm water from the roof of selected buildings and use it for landscape irrigation. It is found that for an average

Table 1. Review of the research on the economic feasibility of RWH (Farreny et al. 2011).

Reference	Location (average rain, mm/year)	Approach of the research	Interest rate (%)	Discount period (year)
Liaw and Tsai (2004)	3 cities in Taiwan (range from 1755 to 350)	Determination of the optimum storage volume of rainwater tanks, considering economic aspects	5	15
Roebuck et al. (2010)	West Yorkshire, UK (700)	Life Cycle Costs (LCC) of RWH	3.5	5
Tam et al. (2010)	cities in Australia (range from 520 to 1597)	Costs of RWH compared to other water supply alternatives	3	20
Ghisi and Mengotti de Oliveira (2007)	Florianopolis, Brazil (1706)	Combination of greywater and RWH systems	1	
Mitchell et al. (2005)	Melbourne, Australia (800)	Role of storm water as substitute of potable water	5.2	50
Zhang et al. (2009)	4 cities in Australia (range from 800 to 1600)	Feasibility of RWH in high-rise buildings (payback period)	6.5	
Eroksuz and Rahman Rahman (2010)	Sydney, Australia (1200)	Determination of the most sustainable RWH scenario for multi-storey buildings (LCC)	5	60
Ghisi and Ferreira (2007)	Florianopolis, Brazil (1706)	Combination of greywater and RWH systems (payback period)		
Farreny et al. (2011)	Granollers, Spain (650)	Cost efficiency of adaptation of RWH system to supply greywater dense neighborhood	0	27

climate condition and current observed water price increase rate (15%), the North tank and the South tank will be able to save water worth of its construction cost within a period of 21 years and 19 years respectively (Imteaz et al. 2011). In Japan Tokyo, Fukuoka, Nagoya domes are used to collect rainwater to use flush toilet and watering plants. The total volume of annual rainfall on the roof at Fukuoka Dome was 52836 m^3, and approximately 75% of the rainwater was utilized and US$ 120,000 was saved in a year (Zaizen et al. 1999). An economic analysis was conducted to supply non potable water to Tancredo Neves International Airport, in Brazil. The airport total roof area is 85000 m^2 and an average annual rainfall is 1305.2 mm, which could provide over 87000 m^3 of rainwater. The payback period of the investments is changing from 2 years to 23 years due to the details of projects (Neto et al. 2012).

2. Material and Methods

2.1 Turkey and world water resources

The world population has experienced continuous growth since the end of the Great Famine. The highest growth rates global population increases above 1.8% per year-occurred briefly during the 1950s, and for longer during the 1960s and 1970s. The global growth rate peaked at 2.2% in 1963, and has declined to below 1.1% as of 2012 (Lal and Stewart 2012). The World and European Union population growth rate have a tendency to decrease after 1960's (Figure 1).

The same behavior can be seen Middle East and North Africa Region and Turkey population growth rate after 1980's. In 2013 the population growth rate of Turkey is 1.256 % slightly larger than the World's population growth rate whereas European Union's population growth rate is 0.217. Although there is a certain decrease in The World's population growth rate, according to the 2012 Revision of the official United Nations population estimates and projections, the world population is reaching 8.1 billion in 2025, and to further increase to 9.6 billion in 2050 and 10.9 billion by 2100 (UN 2013). The population of Turkey is declared as 76 667 864 at the end of 2013 by TUIK. The Turkey population was predicted at 2050 with five different expectations and the least one is 95 million and the highest one is 106 million.

Tahmiscioğlu et al. (2006) gives the water potential of Turkey in details. The total surface runoff within the country reaches almost 193 billion m^3. However, not all of the renewable water resources can be utilized because of economic and technical reasons. Exploitable portions of surface runoff, inflow from bordering countries and groundwater are 95, 3, and 12 billion m^3, respectively. Thus, total exploitable water resources amount of Turkey is 110 billion m^3.

Water usage of various sectors in 2008 are analyzed and 2023 water usage projections are given with Fig. 2 by General Directorate of State Hydraulic Works (DSI 2015). 34 billion m^3 in irrigation, 7 billion m^3 in domestic water supply and 5 billion m^3 in industry totally 46 billion m^3 of water was consumed in 2008. This sum corresponds to only 41% of the available exploitable potential.

According to future projections, the share of irrigation use will decrease from 74% in 2008 to 64% by 2023. On the

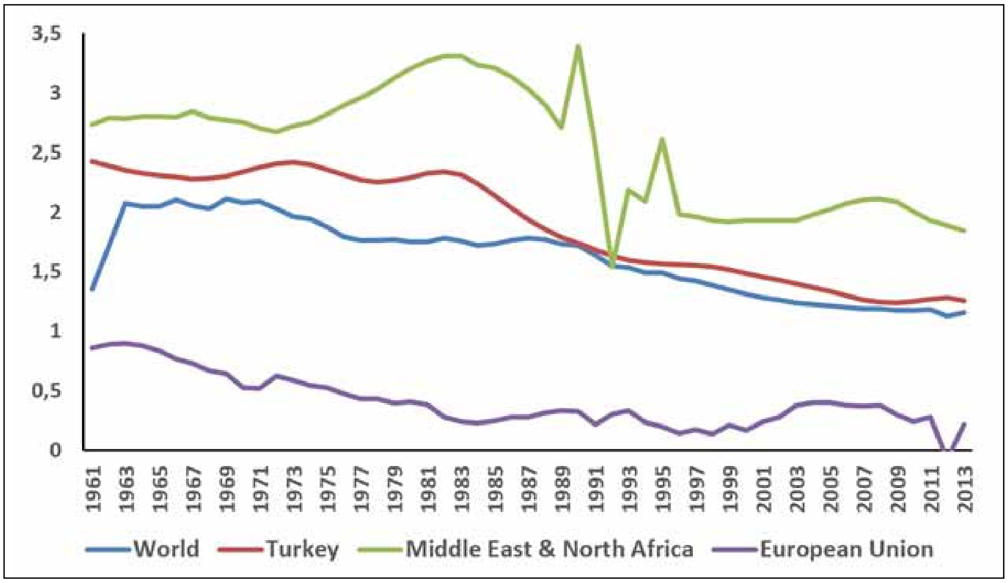

Figure 1. Population growth rate (WWF 2014).

other hand, the domestic and industrial use would increase to 16% and 20% in this period, respectively. In 2023 total water demand will be 112 billion m^3 which is equal to the exploitable water resource of Turkey. Today Turkey's water supplies per person is 1450 m^3 and it will be 1100 m^3 at 2030 and 1030 m^3 at 2050. This means that Turkey is experiencing a definite water stress and will be a country with water scarcity in 30 to 50 years (UNEP 2009). Moreover due to global warming effects, Turkey's climate has 29 mm/100 years decrease trend in annual rainfall and 0.64°C/100 years increase trend in average temperature (DMİ 2015).

Freshwater availability, use and management have been studied on national and river basin scale until recently. However freshwater resources are subject to global changes and trade. Appreciating the global dimension of freshwater resources can be regarded as a key to solving some of today's most urgent water problems. Water footprint (WF) definition based on the total volume of freshwater that is used to produce the goods (Hoekstra 2011). Water footprint has three main components such as; rainwater (green WF), ground and surface water (blue WF) and volumes of water polluted (grey WF). Water footprint of Turkey is 1642 m^3/year/person due to the data in 1996-2005, which is 20% larger than the World water footprint. The WF of Turkey is increased to 1977 m^3/year/person due to increase in production and change in consumption attitudes (WWF 2014).

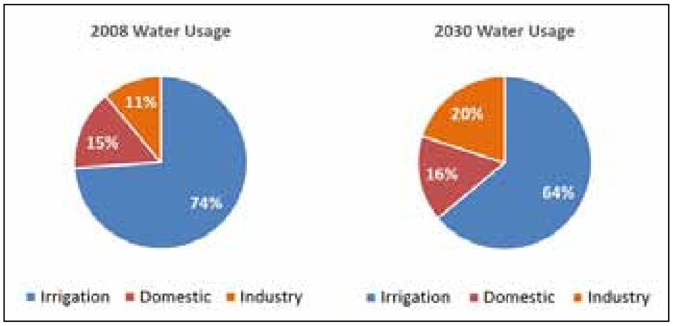

Figure 2. Actual water consumption and projection (DSI 2015).

2.2 Definition of study area

Turkey's diverse regions have different climates because of irregular topography. Annual precipitation of Turkey is given Fig. 3 and receives most of the rainfall in the winter season. Annual precipitation in those areas varies from 580 to 1,300 millimeters. The Black Sea coast receives the greatest amount of rainfall. The eastern part of that receives 2,200 millimeters annually and is the only region of Turkey that receives rainfall throughout the year.

Figure 3. Average annual rain map of Turkey.

Zonguldak province is located at the North West coast of Turkey. The climate of Zonguldak province is significantly changed from the coastal to the inland areas because of the mountains that run parallel to the coast. Monthly averaged temperature distribution is given in Fig. 4. The long period annual average temperature in Zonguldak province is 13.5 °C. Summer average temperature is between 19-22 °C and winter is between 6-8 °C. The maximum mean temperature is 25.2°C in August and the minimum mean temperature is 3.3°C in February.

The long period (1961-2012) annual average precipitation is in Zonguldak province in the coastal areas is 1231.9 mm. The climate of Gökçebey and Devrek district in the inland area of Zonguldak province is Mediterranean type. The mean annual rainfall at Devrek and Gökçebey districts are 785.4 mm and 853.9 mm, respectively. The historically maximum measured rainfall is recorded as 153.7 mm at 22nd of June 1973. Although precipitation is generally as rainfall in coastal regions historically maximum snow depth is measured as 105 cm at 22nd of January 1961. The maximum monthly averaged rain falls in December 158 mm and minimum rain falls in May as 54.4 mm Fig. 5. Furthermore there is regular rainfall throughout the year. Long term monthly averaged rainy days in Zonguldak is given in Fig. 5. The maximum rainy month is January with average 18 days rainfall. On the other minimum average rainy days are seen July with 7.1 days rain fall.

Seasonality index indicates that inter-monthly variations of rainfall amounts are not significant and rainfalls are relatively uniformly distributed within a year. The seasonality index (SI) is calculated as following equation (Walsh and Lawer 1981):

$$SI = \frac{1}{R}\sum_{j=1}^{12}\left| X_j - \frac{R}{12} \right| \tag{1}$$

where, SI is the seasonality index, R is the median annual rainfall and X_j is the median monthly rainfall for month 'j'. SI value of Zonguldak is calculated as 0.29 and the rainfall regime can be classified as Equable but with a different wetter season. A comparatively high rainfall season seems between October and January and average rainfall is 144.5 mm.

2.3 Zonguldak's municipal water resources

Due to TUIK's (2012) municipals water resources and usage statistics report, daily water consumption of Zonguldak is 279 liters per person (Turkey average is 217). About 59% of the Zonguldak municipal water works depend on dams for supplying drinking water, and about 41% uses groundwater where 12% percent is natural source and 29% is groundwater pumping wells. Zonguldak municipal water is mainly supplied from the Ulutan Dam. The dam reservoir has a catchment area of 22.4 km^2 with an annual flowrate of 20.6 hm^3/year. The water demand of the city is about 13 hm^3/year and the dam reservoir is capable to cover the water demand of the city. Ulutan Dam provides the domestic water need of Zonguldak province with an average rate of 1800 m^3/h (0.5 m^3/s).

2.4 Water prices in Zonguldak

The water price in Zonguldak is decided by Municipality Presidency and Municipality Assembly every year. All water distribution system subscribers are grouped due to water usage purpose and essential character of subscriber field of activity. There are 21 different groups in the tariff list with different water price. The minimum water price is 1.40 TL for cubic meter for disabled person's house. Normal house subscriber, government agencies and schools&hospitals water prices are 2.8 TL, 8.00 TL and 6.00 TL for cubic meter respectively. The wastewater cost is also included as 0.80 TL for cubic meter of water. The rate of value added tax for water and wastewater is 8% and added to the water price. Total water prices of cubic meter water for selected subscribers are given in Table 2.

2.5 BEU central campus RWH system analysis

BEU consists of many campus areas such as Ereğli, Alaplı, İncirharmanı, Kilimli, Devrek, Çaycuma, İbni Sina (Medical) and Farabi (Central) Campus distributed in Zonguldak Province. The water requirements of these campus areas are provided by municipal water distribution network. Central campus is laid between Zonguldak City center and Kozlu district (Fig. 6). Each building area is directly connected Municipal water distribution network.

Faculty of Arts and Sciences (FAS), Faculty of Economics and Administrative Sciences (FEAS) and Faculty of Engineering (FE) are located in Central Campus. Besides the faculty buildings BEU Presidency building, student affair office (S.A.O.), main library (M.L.), guest house (G.H.) and sport complex (S.C.) are located in the Farabi campus. Moreover university main dining hall (D.H.) is also located in the central campus. The roof sheathing materials, roof areas, perimeters, ground and roof elevations of all buildings are given in Table 3.

Table 2. Zonguldak municipal water price.

Subscriber	Water price	Waste water	VAT	Total
Disabled persons house	1.4	0.8	0.18	2.38
Normal house	2.8	0.8	0.29	3.89
Government agencies	8	0.8	0.70	9.50
Schools hospitals	6	0.8	0.54	7.34

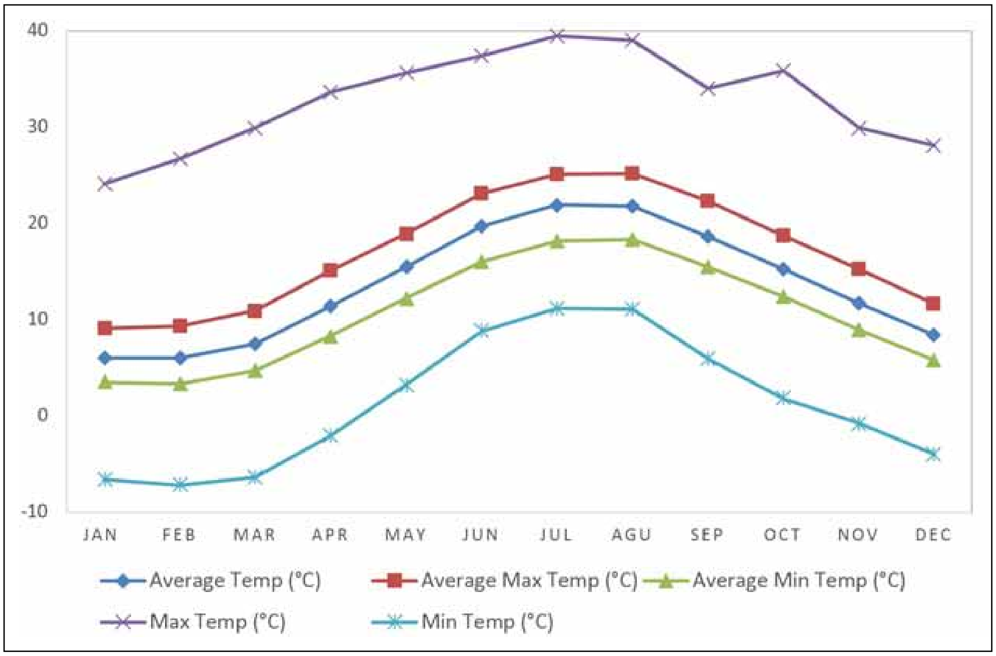

Figure 4. Monthly averaged temperature in Zonguldak.

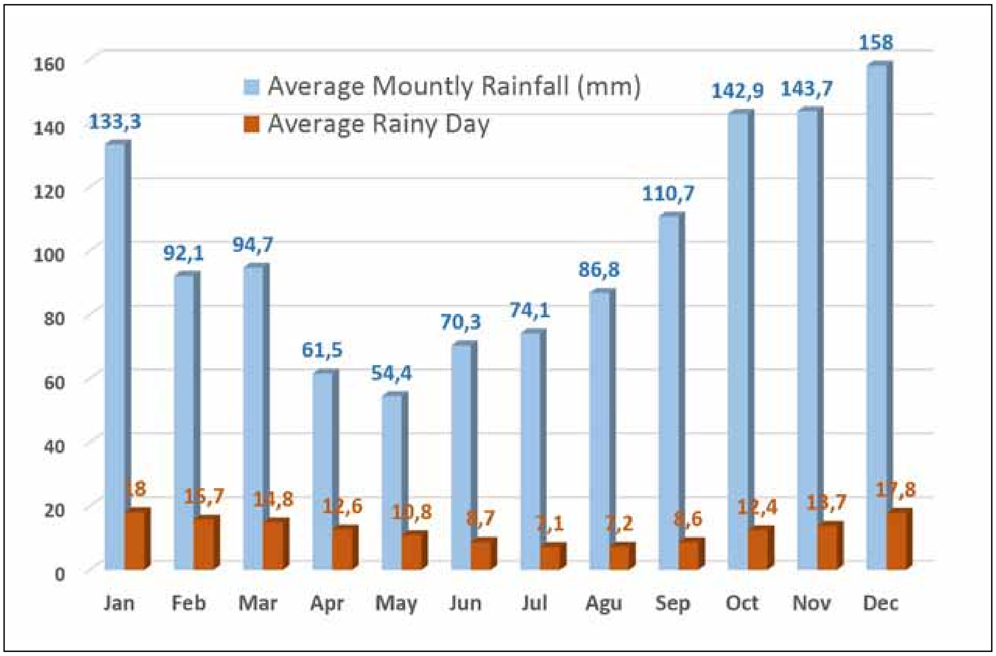

Figure 5. Monthly average rainfalls and numbers of rainy days in Zonguldak.

Figure 6. BEU central campus.

2.5.1 Central campus water consumption analysis

The water consumption rates are obtained by examining water payment bills between October 2012 and October 2013. Water consumption ratios of all buildings in main campus are given in Table 4. University main dining hall uses 15% of all main campus water consumption. Electronic Engineering and both buildings of Faculty of Art and Science water usage are almost equal and cover 39% of consumption of main campus. Minimum water consumption is seen in Sport Complex and Student Affair Office builds as 2% and 3% respectively. Main campus monthly water consumption ratios are given in Table 4. Maximum water consumption is seen in May 2013 when irrigation starts and all students have classes for spring semester. On the other hand minimum water consumption is seen in January and February of 2013 when students are in semester vacation and no need for irrigation in green areas.

2.5.2 Rain water harvesting and roof materials

The roof materials have two distinct affect (quantity and quality) on the rain water harvesting system. The run-off coefficient of roofs varies between 0.9-0.7, due to the roof materials (Gould and Petersen, 1999). Rainwater harvested from any roofing materials requires treatment if

Table 3. Properties of campus buildings

#	Building name	Roof Material	Perimeter (m)	Roof Area (m^2)	Ground Elevation (m)	Roof Elevation (m)
1	FEAS	Metal	240	2210	40	65
2	FAS 1	Metal	176	1590	51	76
3	FAS 2	Concrete	261	2251	62	76
4	Civil Eng. and Environmental Eng.	Concrete	588	5737	55	63
5	Mining Eng.	Concrete	375	2792	57	65
6	Mechanical Eng.	Concrete	491	3932	58	66
7	Electronics Eng. and Main Library	Concrete	450	4108	56	64
8	Engineering Laboratory A	Metal	143	818	75	96
9	Engineering Laboratory B	Metal	102	501	81	100
10	Engineering Laboratory C	Metal	124	688	91	107
11	Presidency Building	Metal	113	519	85	100
12	Student Affair Office	Concrete	134	859	56	64
13	Guest House	Metal	122	583	85	102
14	Sport Complex	Metal	172	1713	55	67
15	Dining Hall	Metal	160	994	64	76

the consumer wanted to use primary or secondary drinking water. It is better to harvest the rainwater after a first flush. Metal roofs are commonly recommended for RHW; but they did not produce superior harvested rainwater quality as compared to the other roofing materials (Mendez et al. 2011).

2.5.3 Rainwater demand characteristics

The water use of commercial and institutional customers involves approximately one fourth of the total quantity of water demanded for an urban area. Although the commercial and institutional customers consume significant portion of total urban water demand, little attention has been focused on the water usage and saving of this sector. This is basically due to the heterogeneous nature of this customer sector and a lack of knowledge regarding end uses of water (Dziegielewsk et al. 2010).

Domestic water usage researches in European countries shows toilet flushing is 35% of total household water demand. Although it is not easy to give certain percentage for outdoor usage and clothes washing water usage, where rainwater can be used without treatment, is not less than 15% of total water demand. Simply, 50% water demand of a house might be supplied by rain water without treatment.

For public buildings non-potable water demand ratio is much higher than a house (Farina et al. 2011). Funk and DeOreo (2011) study shows that 29% water consumption is used only for irrigation in schools. The water consumption profile analysis in the Tancredo Neves International Airport showed that 65% of the registered consumption is used to supply non-potable demands (Neto et al. 2012). Fukuoka Dome rainwater utilization covers 59% of water used for flush toilets and watering plants at the dome (Zaizen et al. 1999). Water use profiles of office buildings in Canada is searched by Morton (2011) and it is vary significantly because of the wide variety of different activities or uses of water within buildings. Typically, % 40 of total demand is used for cooling and heating and % 20 of total demand is used for landscaping which might be supplied from rainwater (Morton 2011).

In the planning BEU RWH system, it is assumed that at least 70% of BEU Campus total water demand is non potable water and might be supplied with rainwater. The possible rain water demand of BEU in 2012-2013 is given in Table 5. The water demand schedule is applied in daily manner for working days of each month. The main dining hall water consumption based on the cleaning of the cooking equipment and service tools and the collected rainwater should not be used without chemical or biological treatment. The Dining Hall water consumption is not added to rainwater demand. However roof of the dining hall is also be used as catchment area and water coming from the water collected from the roof is transferred to the main collection depot.

Table 4. Water consumption ratios.

Buildings	Water Consumptation Ratios (%)	Months	Water Consumptation Ratios (%)
FEAS	5	**January**	8
FAS 1	13	**February**	9
FAS 2	13	**March**	7
Civil Eng. and Environmental Eng.	8	**April**	8
Mining Eng.	9	**May**	10
Mechanical Eng.	4	**June**	9
Electronics Eng. and Main Library	13	**July**	9
Presidency Building	9	**August**	9
Student Affair Office	3	**September**	9
Guest House	6	**October**	9
Sport Complex	5	**November**	8
Dining Hall	15	**December**	8

Table 5. Monthly rainwater demand of buildings (m^3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FEAS	102	109	117	118	42	71	93	50	7	45	117	105
FAS 1	160	144	155	177	203	230	207	289	328	313	110	160
FAS 2	152	156	167	202	242	253	216	274	288	276	111	151
Civ. Env. Eng.	73	54	58	72	88	228	277	245	154	150	86	74
Min. Eng.	146	100	107	124	144	128	95	138	161	160	155	149
Mec. Eng.	74	29	31	45	60	58	46	46	37	46	169	77
Elec. Eng.	184	147	158	218	286	267	208	201	151	157	240	186
Presidency B.	134	121	130	150	173	125	73	151	213	210	175	135
S.A.O.	36	53	57	50	42	37	28	41	48	48	46	35
G. H.	90	90	90	90	90	90	90	90	90	90	90	90
S. C.	34	28	30	33	37	35	28	31	29	28	24	34

3. Results

A spreadsheet based daily water balance model was used considering daily rainfall, contributing catchment (roof) area, spillage/leakage losses, storage volume and water uses. In the model, the primary input value is the daily rainfall amount. Through statistical analysis using historic daily rainfall data one average year selected. The daily runoff volume was calculated from daily rainfall amount by multiplying the rainfall amount with the contributing roof area. Generated runoff was diverted to the connected available storage tank. The model calculates daily storm water use, daily water storage in the tank, daily overflow. The water balance equation for the system can be expressed as follows.

$$V_t = \sum_{t=t0}^{t} (Q_{i,t} - Q_{s,t}) \tag{2}$$

Where, Q_i is runoff from the roof (m^3/day), Q_o is overflow from the tank (m^3/day), Q_s is the rainwater supply (m^3/day), V is tank volume (m^3), t is elapsed time (in days) and V_t is the storage volume of the rainwater in tank (m^3) at time t.

Costs and maintenance expenses may be compensated by benefits-water savings and environmental improvements generated by the installation of the RHW system. The economic analysis has been performed by using the Net Present Value (NPV) model given with equation (3), where B_t are the benefits and C_t the costs in the period t and where i is the discount rate.

$$NPV_T = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+i)^t} \tag{3}$$

Capital costs have been accounted for in 2014 with the unit prices declared by government agencies for construction works. The initial capital cost of RWH system is analyzed by considering three main groups of construction works. Those are harvesting, storage, and distribution. The operation and maintenance cost is calculated for all service life of system. The details of initial and long-term cost components are given in Table 6.

3.1 Rainwater supply and distribution system design

All buildings in main campus are considered in the Rainwater harvesting system design. Water supply and demand analysis are based on daily precipitations and demands. Initial and 30 years' service life expenditures are considered in economic analysis. Two different rainwater harvesting and distribution systems are proposed. Each system is analyzed in details and results are compared.

3.2 Separated rainwater harvesting and distribution system

The first proposed system is based on the idea of self-sufficient buildings. A RHW system, with adequate collection tank and distribution system is separately designed for each building in campus. Collected rainwater from catchment area of each building is used at that building and green area located around it. Main advantages of the separate system are no construction works required in the campus area, small tank volume and basement area, starting water saving in an expeditious manner. The proposed separated rain water harvesting and distribution system might be applied to each building in different time. The application of all project can be extended in large period without increase in investment cost.

Each building RWH system is designed separately and cost is analyzed with considering building dimension. The details of the designed separate RWH systems are given in Table 7. The separated RWH system requires 11 collection tank which volumes are varying between 20 m^3 and 180 m^3. The tank volume is decided with considering the maximum rainwater usage constrain. Separated RWH system total proposed tank volume is 960 m^3. Separated system total water demand and withdrawal rainwater volumes are 15989 m^3, and 11077 m^3 respectively. The maximum rainwater compensation ratio is obtained at FEAS building with 99.4%, the minimum compensation ratio is obtained at Presidency building with 26.1%. System overall compensation ratio is almost equal to 70%.

Table 6. Components of RWH system cost.

Initial Cost	Harvesting	Trench works
		Storm sewers
		Manholes
		Pavement works
		Filter
	Storage	Earth movements
		Rainwater tank (built in situ)
	Distribution	Pumping station
		Distribution system
Operation and Maintenance Cost	Operation cost	Pump electricity consumption
		UV Filter electricity consumption
	Scheduled maintenance	Repair/replace pump
		Replace UV lamp
		Clean filters/replace filter media
		Annual cost of consumables
		Clean catchment surface
		Water quality treatment items

Table 7. Separate RWH system characteristics.

	Yearly Demand (m^3)	Tank Volume (m^3)	Empty Tank Days	Withdrawal (m^3)	Overflow (m^3)	Compensation Ratio (%)
FEAS	976	80	4	969	1100	99.4
FAS 1	2476	120	114	1183	285	66.1
FAS 2	2488	120	136	1454	655	58.5
Civ. Env. Eng.	1559	140	18	1410	3962	90.5
Min. Eng.	1607	160	19	1521	1092	94.6
Mec. Eng.	718	50	3	695	2987	96.9
Elec. Eng.	2403	180	42	2072	1775	86.3
Presidency	1790	20	269	467	18	26.1
SAO	521	35	40	465	340	89.2
G. H.	1080	35	203	493	4	47.8
S. C.	371	20	24	348	1255	93.8

Faculty of Art and Science, Presidency and Guest House buildings rain water compensation ratios are less than overall average compensation ratio. When the tank overflow data of those buildings are evaluated, it is seen that the overflow water volume is far away from supplying required rainwater. Increasing collection tank volumes do not supply enough water to increase the compensation ratios of the buildings within certain amount. The catchment area of those buildings are not enough to supply adequate rainwater to the buildings. On the other hand when the buildings compensation ratio with larger than overall compensation ratio are considered, the overflow rainwater volumes of those buildings has a capacity to supply other buildings. A connected system may increase overall compensation ratio of main campus RWH system.

The calculated project cost, first year and project service life savings and payback period of all buildings are given in Table 8. The payback period of second building of Faculty of Art and Science and Electronic Engineering building are 5 years. The longest payback periods are calculated as 13 years and 12 years for Sport Complex buildings and Mechanical Engineering Building respectively. The total project cost of separated rainwater harvesting system of Bulent Ecevit University Main Campus is about 450 000 TRL, first year saving is 83 000 TRL and service lifesaving is 828 000 TRL.

3.3 Connected rainwater supply and distribution system

The second proposed system is based on connected rainwater collection and distribution system in campus and a large central collection tank. The rainwater harvested from campus buildings except the Faculty of Economics and Administrative Science building is collected in a central tank constructed at the 50 m elevation and distributed to the buildings and green areas. Since Faculty of Economics and Administrative Science building is located the lowest part of campus area it requires to pump harvested rainwater to the central collection tank. Moreover with previously proposed separated RWH system a self-sufficient RWH and distribution system is planned for Faculty of Economics and Administrative Science building. The Faculty of Economics and Administrative Science building is excluded from the central rainwater collection and distribution system.

The details of connected RWH system characteristics and economic analysis results are given in Table 9. Total catchment area of the main campus buildings is 27085 m^2. The proposed connected system central tank volume is 1000 m^3 which is obtained by optimizing with maximum rainwater saving volume constrain. With adding the volume of Faculty of Economics and Administrative Science building rainwater tank, the total collection tank volume becomes 1080 m^3 for second alternative project. Overall compensation ratio of connected system is almost 87%. The overall payback period of connected system is 6 years. The total cost of connected system is almost 17% more expensive than the separated system. However project whole life saving is 50% higher than separated system.

4. Conclusion

The study shows that large amount of rainwater can be used in BEU central campus as low quality water without treatment which is an effective and economic solution for drinking water saving. Application of dual rainwater and drinking water distributions system in public buildings is more convenient than residential buildings which makes RWH system more economic. The tank volume expense is one of the main parts of RWH system investment. The payback period of the investment is directly related the initial expense and it is extended with tank volume.

The total education expenditures in Turkey is just 2.5% of gross domestic product. The share of public universities is less than one third of national educational budget. All consumptions is paid from the total budget of university and water consumption cannot be regarded as little. Hence the payback period of RWH is short, it will be a source to found university budget after payback period. The proposed RWH system will be a first application and a reference model to other universities and schools.

This is the first RWH system application cost-benefit analysis study to supply public university water demand in Turkey. Other than social and ecological benefits, in urban areas RWH system is an alternative to conventional water supply system and the benefit of the system is evaluated with drinking water price. Since municipal water price is high for public buildings in Zonguldak, RWH systems designed for BEU central campus is an economical alternative.

The basic usage areas of untreated rainwater is toilet flushes and irrigation. BEU main campus facilities yearly water demand variation is analyzed. Two different alternative application project is designed to supply low quality water requirements of campus facilities. The first one is the separate system in which rainwater is collected and used in the same building. The second proposed project is based on a central collection and distribution system of rainwater. BEU campus separated RWH system supplies 70% of low

Table 8. Separate RWH system economic analysis.

	Project Cost (TRL)	First Year Saving (TRL)	30 years Savings (TRL)	Payback Period
FEAS	37,705.00	7,269.00	73,835.00	6
FAS 1	42,671.00	8,874.00	95,100.00	6
FAS 2	48,701.00	10,903.00	126,500.00	5
Civ. Env. Eng.	70,938.00	10,575.00	99,041.00	8
Min. Eng.	63,914.00	11,409.00	120,506.00	7
Mec. Eng.	41,740.00	5,211.00	33,522.00	12
Elec. Eng.	72,773.00	15,540.00	184,686.00	5
Presidency	15,199.00	3,504.00	30,108.00	6
SAO	20,580.00	3,485.00	24,350.00	9
G. H.	20,028.00	3,700.00	28,706.00	8
S. C.	18,032.00	2,610.00	11,606.00	13

Table 9. Connected RWH system characteristics and economic analysis

	All buildings	FEAS	Overall
Yearly Demand (m^3)	14273	976	15249
Tank Volume (m^3)	1000	80	1080
Withdrawal (m^3)	12246	969	13215
Overflow (m^3)	12572	1100	13672
Compensation Ratio (%)	85.8	99.4	86.7
Project Cost (TRL)	491,928.00	37,705.00	529,633.00
First Year Saving (TRL)	91,846.00	7,269.00	99,115.00
30 years Savings (TRL)	1,172,645.00	73,835.00	1,246,480.00
Payback Period	6	6	6

quality water demand and service lifesaving is 828,000 TL. The connected system supplies 87% of low quality water demand of campus and service lifesaving is 1,247,000 TL. The connected rainwater harvesting system approach has a better performance to handle variable demand and supply conditions. Although there is not much difference on the total tank volumes connected system service life is saving is 50% higher than separated system.

Zonguldak municipal water is mainly supplied from the Ulutan Dam constructed on the Ulutan River. Annual flowrate of Ulutan River is 20.6 hm^3/year. The water demand of the city is about 70% of the river all water potential. It is almost reached the limit of usable capacity of the river. Beside, many ground wells are drilled around province and certain amount of water is supplied from the ground water. Proposed RWH project reduced the water discharged from these sources.

5. References

Basinger, M., Montalto, F., Lall, U. 2010. A rainwater harvesting system reliability model based on nonparametric stochastic rainfall generator. *J. Hydr.,* 392 (3-4): 105-118.

Bates BC., Kundzewicz ZW., Wu S., Palutikof JP. 2008. Climate change and water. Technical paper of the Intergovernmental Panel on Climate Change. Geneva: IPCC Secretariat; 210 pp.

Domènech, L., Sauri, D. 2011. A comparative appraisal of the use of rainwater harvesting in single and multi-family buildings of the metropolitan area of Barcelona (Spain): social experience, drinking water savings and economic costs. *J. Clean. Pro.,* 19 (6-7): 598-608.

DSI 2009. Water Report 2009, General Directorate of State Hydraulic Works, Ankara.

Dziegielewsk, B., Kiefer, JC., Opitz, EM., Porter, GA., Lantz, GL., DeOreo, WB., Mayer, PW., Nelson, JO. 2000. Commercial and institutional end uses of water, AWWA Research Foundation, Denver, USA.

Eroksuz, E., Rahman, A. 2010. Rainwater tanks in multi-unit buildings: a case study for three australian cities. *Res. Cons. Recyc.* 54 (12): 1449-1452.

Farina, M., Maglionico, M., Pollastri, M., Stojkov, I. 2011. Water consumptions in public schools. *Procedia Eng.*, 21: 929–938.

Farreny, R., Gabarrell, X., Rieradevall, J. 2011. Cost-efficiency of rainwater harvesting strategies in dense mediterranean neighbourhoods. *Res. Cons. Recyc.* 55(7): 686-694.

Funk, A., DeOreo, WB, 2011. Embedded energy in water studies study 3: end-use water demand profiles. CALMAC Study ID CPU0052 Volume 1 of 1 Main Report, California Institute for Energy and Environment.

Ghisi, E., Ferreira, DF. 2007. Potential for potable water savings by using rainwater and greywater in a multi-storey residential building in southern Brazil. *Build. Env.* 42 (7): 2512-2522.

Ghisi, E., Mengotti de Oliveira, S. 2007. Potential for potable water savings by combining the use of rainwater and greywater in houses in southern Brazil. *Build. Env.* 42: 1731-1742.

Gould, J., Nissen-Petersen, E. 1999. Rainwater Catchment Systems for Domestic Supply, Intermediate Technology Publications.

Hoekstra, AY., 2011. The global dimension of water governance: why the river basin approach is no longer sufficient and why cooperative action at global level is needed. *Water*, 3: 21-46.

Imteaz, MA. Shanableh, A., Rahman, A., Ahsan, A. 2011. Optimizations of rainwater tank design from large roofs: a case study in Melbourne, Australia, *Res. Cons. and Recycling*, 55 (11): 1022–1029.

Lal, R., Stewart, BA. 2012. Soil water and agronomic productivity. CRC Press.

Liaw, CH., Tsai, YL. 2004. Optimum storage volume of rooftop rain water harvesting system for domestic use. *J. Am. Water Res. Ass.: 901-912.*

Mendez, CB., Klenzendorf, JB., Afshar, BR., Simmons, MT., Barrett, ME, Kinney, KA., Kirisits, MJ., 2011. The effect of roofing material on the quality of harvested rainwater. *Water Res.*, 45: 2049-2059.

Mitchell, VG, Taylor, A, Fletcher, TD, Deletic, A. 2005. Storm water reuse. Potable water sub-stitution for Melbourne. ISWR Rep. No. 05/12. Australia: Monash University.

Morton, J. 2011. Water Management: A Benchmark for Canadian Office Buildings Report. REALpac.

Neto, RFM., Carvalho, IC., Calijuri, ML., Santiago, AF. 2012. Rainwater use in airports: A case study in Brazil resources. *Res. Cons. Recyc.* 68: 36-43.

Patel, UR., Patel, VA., Balya, MI., Rajgor HM. 2014. Rooftop rainwater harvesting (rrwh) at spsv campus, visnagar: gujarat - a case study, *Int. J. Res. Eng. Technol.*, 3 (4): 821-825.

Reobuck, RM., Oltean-Dumbrava, C., Tait, S. 2010. Whole life cost performance of domestic rainwater harvesting systems in the United Kingdom. *Water Env. J.*, 25 (3): 355-365.

DMİ 2015. http://www.mgm.gov.tr/FILES/iklim/turkiye_iklimi.pdf.

Tam, VWY., Tam, L., Zeng, SX. 2010. Cost effectiveness and tradeoff on the use of rainwater tank: an empirical study in Australian residential decision-making. *Res. Cons. Recyc.* 54 (3): 178-186.

Tahmiscioğlu, MS., Karaca, Ö., Özdemir**, AD.,** Özgüler**, H. 2006.** Possible effect of the global climate change on water resources and floods in Turkey. International Conference on Climate Change and the Middle East Past, Present and Future, ITU, Istanbul/Turkey.

TUIK 2015. Belediye Su İst. http://www.tuik.gov.tr/PreHaberBultenleri.do?id=16171

UNEP 2009. Rainwater harvesting: a lifeline for human well-being first. J. Barron, ed., Stockholm.

UN 2013. World population prospects, the 2012 Revision, Key Findings and Advance Tables. United Nations, New York.

Villarreal, EL., Dixon, A. 2005. Analysis of a rainwater collection system for domestic water supply in Ringdansen, Norrköping, Sweden. *Building and Env.*, 40 (9): 1174-1184.

Walsh, RP., Lawer, DM. 1981. Rainfall seasonality: description, spatial patterns and change through time. *Weather*, 36: 201-208.

WWF 2014. Living planet report 2014, Species and spaces people and places, WWF International 2014.

Worm, J., Van, HT. 2006. Rainwater harvesting for domestic use. Agromisa Foundation and CTA. Wageningen.

Zaizen, M., Urakawa, T., Matsumoto, Y., Takai, H. 1999. The collection of rainwater from dome stadiums in japan. *Ur. Water*, 1: 355-359.

Zhang, Y, Chen, D, Chen, L, Ashbolt, S. 2009. Potential for rainwater use in high-rise buildings in Australian cities. *J. Env. Man.* 91: 222–226.