ASSESSMENT OF POTENTIAL OF ROOF-TOP RAINWATER HARVESTING IN IBB CITY, YEMEN

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ABSTRACT

Although arid and semi-arid regions are the most vulnerable regions to water scarcity, it is witnessed that large amount of fresh rainwater is lost by evaporation or to the sea. Further, floods frequently cause damage in cities and villages. Therefore, rainwater harvesting (RWH) may be vital for securing alternative water resources in such regions. This paper aims to evaluate the present and future water situation in Ibb City, Yemen, and hence assess the impact of RWH in closing the water gap. First, a survey of available water resources and water demands in the study region has been carried out based on available data and studies from NWRA and IWSLC, upon which the present and future water deficit until 2050 has been determined. Further, a field survey has been carried out to assess water quality and consumer opinion. Except for biological parameters, it was found that all water quality parameters were within acceptable limits according to WHO and Yemen water law. The collected water would be suitable for drinking after use of a suitable filter and roof cleaning. Based on available data and a per capita water demand of only 70 liters per capita per day (lpcd), the water deficit has been estimated at 25% in 2015 reaching 48% by 2050. In order to close this gap, the potential quantity of water that could be secured through water harvesting from the roofs of all buildings has been calculated through the utilization of GIS maps and the rational method. Three scenarios for estimating the amount of RWH have been considered. The first scenario assumes tapping the maximum potential and supplying the remaining quantity from the local corporation to reach 70 lpcd. The second scenario assumes the water provided by the corporation is fixed at the present supply rate of 43 lpcd since it has a lower cost for the consumer and supplies the shortage (27 lpcd) from harvested water. The third scenario considers the worst conditions like wars and wells drying, so it is assumed that the per capita demand shall be only 34 lpcd to be supplied solely by RWH. The first scenario showed a surplus of 15.2% at the beginning of implementation, but reaching a 7.1% deficiency in 2050. The second scenario resulted in a 10% surplus at the beginning, reaching 12% deficiency in 2050, while in the third scenario no deficiency would result, as the per capita water demand has been assumed to be according to the potential RWH. Economic criteria have been applied to select the most suitable storage tank design. Further, analysis on the feasibility and economical studies of the scenarios showed that the lowest cost of one cubic meter of harvested water is 1.70 USD when applying the first and third scenarios.

Keywords: Rainwater Harvesting, Rooftop, Rainwater Quality, Economic Analysis, Storage Tank

1 INTRODUCTION

Water scarcity and deterioration of its quality have become one of the biggest challenges all over the world. Yemen, which is one of the world's driest countries, suffers from severe water scarcity. Yemen is categorized as an arid to hyper-arid country with no surface water except what is coming from the rainfall. The renewable water resources in Yemen, sum up to an average of 2500 million m^3/year, while the total water consumption in Yemen is about 3400 MCM/year, which means that the deficit is about 900 MCM. The balance is covered through deep groundwater, which is being depleted at an alarming rate (Aklan, 2011).

One of the most effective solutions to reduce the water crisis in Yemen is Rain Water Harvesting (RWH) which prevents as much as possible rainfall from being wasted.

The study area in this research is Ibb Governorate which is situated in the southwestern part of the highland region of Yemen, between (43^{o} 40'- 44^{o} 37'E and 13^{o} 45'-13^{o} 25'N) at a distance of about 200 Km to the south of Sana'a, the capital of Yemen (Fig. 1) with total population of 2,712,859 inhabitants (2013). Ibb is considered as the fourth largest governorate in Yemen and its area is around 5300 Km^2.

Figure 1. Location of Ibb City-Yemen

This study will be conducted in an area about 5300Km^2. The elevation ranges between 500m and more than 3000m above sea level. It is considered as one of the most important rainfed agriculture areas in the highland region, and could be defined as an area that depends basically on rainfall and partly on irrigation systems for crop production. The study area is located in semi-arid zone (Al-Mashreki ,2011). Annual rainfall generally varies between 300 and 900 mm, with some years having exceptionally high rainfall exceeding 1200 mm. The average total amount of potential evapotranspiration is estimated at 1450 mm/year (Acharmana, 2006). There is little rain from November to February, but for the rest of the year there is around 100mm of rain per month. The average annual rainfall is around 371.3 Mm^3 / year. Temperatures are warm, averaging about 30 °C in the day but nights are quite cool.

Ibb has an extremely dense rural population, with densities of up to 500 people/km² being normal in the wettest areas. The expected number of residents up to 2050 has been estimated based on the population division report of the United Nations, version (2010). The city of Ibb has been chosen as a case study because it has the most rainfall during the year.

On the basis of physiographic analysis of the satellite image and topographic data at 100 m contour interval, five major physiographic units' data were delineated. Low land with altitude less than 1000m occupies about 8% of Ibb area, mid land with altitude 1000-1500 m occupies about 23%, high land with altitude 1500-2000 m occupies about 26%, upper land with altitude 2000-2500 m occupies about 24%, and high mountains with altitude more than 2500 m occupies about 19%.

The problem at hand is an increasing demand for drinking water compared to a severe shortage in the resources available and the increase in random drilling for groundwater wells. This has led to contamination of the water and an increase in salinity and mixing with sewage. In addition to the ongoing crisis, which is general to Yemen, specific problems in Ibb City, of concern are: A significant shortfall in the level of non-renewable groundwater as a result of indiscriminate drilling of wells; paving of many of the streets has led to a lack of recharge of groundwater and surface water; pollution of water in Ibb City; flow of the rain water into the valley and then to the sea without beneficial usage; and the increase of water price up to (6-15) $ for each m^3.

The objective of this study is to assess the feasibility of Roof Top Rain Water Harvesting (RTRWH), in addition to assess efficiency, adequacy and quality of the harvested water as a source for drinking or for other household uses. The expected outcomes from this research are summarized as follows: (1) reduce the consumption of groundwater; (2) get clean drinking water with enough quantities during drought periods; (3) rationalize the use and reduce the cost of water; (4) set the size of the water reservoir to minimize cost; (5) determine the quality of harvested water; (6) increase community awareness about the importance of water conservation.

RTRWH is one of the micro-catchment RWH methods. It consists of catchment surface (the collection surface from which rainfall runs off), gutters and downspouts (channel water from the roof to the tank), leaf screens, first-flush diverters, roof washers, one or more storage tanks, and delivery system. The first and the earliest RWH system was built in the Middle East in Jordan where researchers have found signs of early RWH structures which are believed to have been constructed over 9000 years ago (Brauch et al. 2003). In North Yemen, the earliest WH system dates back to at least 1000 B.C. which diverted enough flood water to produce agricultural products (Prinz, 1996; Taher and Saleh, 2010). For rainwater or any other water resource, there are three factors that determine water quality. The first and most important one is the biological factor followed by the more involved chemical factor and the last one is the physical factor. (Rain Water Quality Guidelines, 2008). Assessment for the whole system of RTRWH is an essential step. Mapping the risks of contamination is considered the main objective of the RTRWH system assessment. Such mapping helps to take the appropriate measures to limit the contaminations which should be a preliminary step before thinking about end-of-pipe solutions such as filtration and treatment. Mosley, (2005) presented common contaminations that could be found in rainwater systems. Many researchers have discussed appropriate components of RTRWH systems to assure water quality (Mosley, 2005; Taher & Saleh, 2010; Villarreal & Dixon 2005; Rain Foundation, 2008; Zhu et al. 2004; and others).

Recent studies in Yemen on water harvesting indicate that villagers in the mountainous areas have been well acquainted with WH systems for hundreds of years (Tahir, 2002 as cited in Noman, 2006). A study of potential rooftop rainwater harvesting in Sana’a was carried out by Aklan (2011). The study results showed that the potential amount of rainwater harvested from Sana’a City rooftops is around 6.4 MCM / year. Rainwater quality was assessed as well. A study of documenting the experiences and approaches for water harvesting was carried out by Muhssen et al. (2010). A research aiming at diagnosing the current water situation in Ibb City was conducted by Al-Qadri (2010). He found that natural and human characteristics were the most important factors causing the current crisis. Moreover, the study indicated that WH is suggested as a successful solution for the current water-related problems and issues in the current situation in Ibb.

Aklan et al (2019) discussed RWH as one of decentralized systems in Sanaa City suitable for war condition in Yemen. A multicriteria analysis (MCA) framework to identify and rank suitable sites for different indigenous RWH systems in data-poor areas has been developed by Aklan et al (2022). Sanaa Basin, Yemen has been chosen to be a case study for this research. Yahia et al (2023) aimed to develop a framework for assessing the urban water of Ibb city. They found that urban water in Ibb is insufficient to meet basic needs.

2 RESEARCH METHODOLOGY

The methodology consisted of the following steps: (1) Relevant data about the study area were collected; previous studies and literature review related to Ibb City were studied. Social Fund for Development (SFD) was visited many times to get an overview of their experience in the field of WH. As well as Ministry of Water and Environment (MWE), other authorities and institutions including National Water Resources Authority (NWRA), Ibb Water and Sanitation Local Corporation (IWSLC), and climate stations were visited either for key informant interviews or collecting related data. (2) Water quality surveys were through collecting and analyzing 10 samples of rainfall. (3) ArcGIS and AutoCAD programs were used to digitize 2014 satellite images of Ibb City and combine it with annual rainfall isohyets map. The Rational Method was then used to calculate the potential quantity of rainwater that can be harvested from the rooftops of Ibb city. (4) Matrix for the selection process of tanks types has been developed based on the factors of cost, required capacity and space area availability (5) The expected cost was estimated by using official documents of the costs of selected techniques from previous projects. (5) Calculating the cost of cubic meter, and building a framework for conducting a comprehensive economic analysis for the water harvesting and the water supply in the technical and financial aspects.

2.1 Rainwater Sampling:

Ten samples were tested at the IWSLC labs after they were collected from the locations and analyzed for physical and microbiological constituents according to standard sampling and analysis procedures. Although a larger number would have been more indicative, this was the number possible given the limited available budget.

2.2 Calculation of Water Harvested Quantities and Cost

The total quantities that proposed techniques can harvest have been calculated according to their volumes, numbers and effective rainfall. The potential quantity of harvested rainwater from rooftops has been calculated using rational method, which is considered the most popular method for small catchments. Moreover, it is known to be the preferable method for designing systems in urban areas. This method is unanimously used with all RTRWH studies reviewed in calculating the roof top surface runoffs. Runoff Coefficient is estimated to be 0.95. The city is divided into six zones according to the rooftops area. (See Table 1)

Table 1. Classified Rooftops Area

Rooftop Area (A) m^2	A (<180)	180<A<330	330<A<640	640<A<1500	1500<A<4000	4000<A<5000	Total
TYPE OF BUILDING	Residential				Administrative	Hospital	
	A	B	C	D			
COUNT	14867	5591	1184	182	17	1	21842
AVERAGE AREA (m^2)	109	234	422	866	1966	4513	141
MIN AREA (m^2)	50	180	330	641	1503	4513	0
MAX AREA (m^2)	180	330	640	1497	2877	4513	0
SUM AREA (m^2)	1627646	1310248	499750	142902	33414	4513	3802929
PERCENTAGE (No,)	68.11	20.74	4.39	0.61	0.06	0.004	100
PERCENTAGE (area)	44.61	34.45	13.14	3.76	0.88	0.12	100

3 RESULTS AND DISCUSSION

3.1 Water Sampling, Results and Discussions:

The results documented in this research are the first to deal with harvested rainwater quality in Ibb. Here in this section chemical and physical results of water samples are given and discussed. Table 2 shows physical and chemical parameters analysis results compared to WHO (1993) drinking water guidelines. The results of physical and chemical tests were found to be less than maximum and minimum values of the international standards of health organization and NWRA or Yemeni standard code. The rainwater harvesting system (RWH) showed validity for drinking, despite the surface not being clean and the unavailability of first flush equipment.

3.2 The Current Water Supply

There are three major water supply sources in Ibb. The first is Local Corporation (LC) Water Supply; the network was originally installed in 2002. Then, it has been expanded and improved in 2006 by Dar Al-handasah. The second is Private Wells and Tankers; there are five main stations for tankers (in Arabic named Farza) where the tankers congregate in recent times. These tankers fill up from over 80 wells around the edge of the city. The price of tankers mainly depends on two criteria: the quality of the water, and the distance needed to deliver the water to customers. Additionally, there are other factors such as the location of the houses; especially if there is a considerable uphill climb, and the delivery to several story building which adds to the price. The sale price by tankers to houses according to tanker drivers has been raised recently. For example, the prices ranged from (5000 – 8000) YR per trip to (8000 – 15000) YR due to the increase in fuel price (petrol & diesel). The third water supply source is desalinated water at shops (bottled water). Water processing companies (locally called "*Kawther*") have proliferated since 1990 due to the poor quality of the LC and tanker water (JFA, 2011). Water is brought from companies whose water has a reasonably good quality. The salt is removed using desalination stations. These companies distribute water to shops by lorries. The lorries carry the water in plastic containers (known locally as "dabba"). The amount of water held in these containers ranges from 5 to 10, and occasionally 20 liters of water.

3.3 Household Consumption

A survey on domestic water supply, storage, and usage was conducted among 424 households in some local communities, for the aim of assessing the overall volume of desalinated water demand, and the willingness to pay by the households given the current conditions. Moreover, a comparison between areas which have the service of piped municipal water supply and those which have not. Another comparison was also made between different income groups. The selection of sample location was based on two criteria: random point selection, and population density.

Piped water is generally supplied by the LC, and it is reported to be of low quality, therefore, is rarely drunk. The inadequacies of the piped supply lead many households to supplement their water supply by purchasing water from tankers. Some tankers are filled up with good quality groundwater from valleys, while others are filled up with water of a poor quality. The main source for drinking purpose is bottled water, which is obtained from wells, treated at various commercial plants around the city and supplied in plastic cans. Mineral water, another alternative source for drinking, is usually available in 0.75 liter bottles, but it is more expensive than bottled water. The use of LC, tankers, and bottled water are estimated to be 5, 22, 43 l/c/day consequently.

Table 2. Physical, And Chemical Parameters Analysis Results for Rainwater That Have Been Collected from Different Locations (Gutters)

Parameter	Result										Average	WHO
	Sample (1)	Sample (2)	Sample (3)	Sample (4)	Sample (5)	Sample (6)	Sample (7)	Sample (8)	Sample (9)	Sample (10)		
							Physical Analysis					
E. CONDUCTIVITY	105.3	54.1	141.7	170.7	181.4	107.4	46.3	124.4	79	140	115.03	400-1500
T.D. S	68.5	35.2	92.1	111	117.9	69.8	30.095	80.86	51.35	91	74.78	1000
PH	7.43	7.05	7.66	7.4	6.99	7.02	7.7	7.1	7	7.2	7.25	6.5-8.5
							Chemical Analysis					
ALKALINITY	45	35	75	90	85	65	60	80	65	85	68.5	500
BICARBONATE HCO3	54.4	42.7	91.5	109.8	103.7	79.3	73.2	97.6	79.3	103.7	83.52	150-500
TOTAL HARDNESS	60	45	45	50	85	70	60	75	60	75	62.5	100-500
CALCIUM CA++	16	12	12	18	28	18	16	24	20	22	18.6	75-200
Magnesium Mg++	4.87	7.299	7.299	1.2	3.6	6	4.8	3.6	2.4	4.8	4.58	30-50
Ammonia	0.15	0.012	0.001	0.01	0.002	0.05	0.004	0.003	0.113	0.098	0.04	0.05-0.5
Nitrate NO3	5	10	4	1	5	4	7	5	5	6	5.2	25-50
Nitrite NO2	0.028	0.044	0.026	0.0342	0.0205	0.034	0.012	0.002	0.038	0.015	0.025	0.1
Chloride Cl-	33.04	28.03	44.55	26.02	61.79	28.53	20	22.03	17.52	23	30.45	250
Sulphate SO4--	29.3	10.2	19	21.1	37.2	17.5	6.5	17.8	7.3	26.1	19.2	25-400
Potassium K+	1.57	0.26	3.37	4.96	2.57	0.78	0.3	0.48	0.32	2.07	1.66	12--8
Total Iron Fe	0.238	0.119	0.105	0.12	0.109	0.06	0.052	0.135	0.117	0.237	0.12	0.3-1
Copper Cu++	0.068	0.145	0.087	0.198	0.126	0.033	0.053	0.094	0.153	0.105	0.11	0.5-1

3.4 Water Balance

Based on the data from ILCWS and JFA, the prediction for the coming years up to 2050 is done assuming that capita water consumption is 70 liters per day ; non-domestic requirement is estimated 13 % from domestic use depending on reviewing the percentages of water consumption for the period starting from 2000 till 2010; The increase in water production and consumption of water from tankers and bottled sources are estimated around 2 % as a result of population growth; and the losses in IWSLC water are assumed to be constant at 23 % based on the average percentage of the period between (2010-2014). The water balance has been discussed according to three different assumed scenarios, as following.

First scenario: It is assumed that the extreme need to harvest all rainwater from rooftops, where they represent about 34 lpcd. The water productivity was fixed according to the current situation of IWSLC for including the large consumption of groundwater, rapidly decrease of the level of ground water with random digging by the people (private wells represent 75% of the wells in the reservoir).

Second scenario: This represents the dependence on local water and fixing its productivity on the current situation. This is estimated to be 5,301,715 m3/year, with rain water harvesting to cover the shortage which represents 38% of the need (about 27 lpcd). The harvesting tanks calculated on this basis.

Third scenario: It is assumed to not dependent on any other resources except what is harvested from the houses roofs which equals to 34 lpcd. The harvesting tanks calculated on this basis.

For scenarios 1 and 3, the total quantities that can be collected from roof top in Ibb City have been calculated based on an average annual rainfall of 950 mm, the total roof area of about 3,80 Km^2, the runoff coefficient equals to 0.95 as most roofs are made of concrete. Based on this, the total water harvested is estimated at about 3.27 Mm^3/year. Table 3 summarizes the results of calculations of the actual amounts of harvested water available, the designed volume of the tanks for each area, the cost of each type of tank, and the total costs that have been calculated counting on gathered information.

Table 3. The Proposed Rooftop Harvesting Tanks for Scenarios 1 & 3

TYPE OF BUILDING	**Residential**				**Administrative**	**Hospital**
	A	**B**	**C**	**D**	**E**	**F**
Average Roof Area (m^2)	109	234	422	866	1966	4513
Estimated Yield (m^3/year)	99	212	381	782	1774	4073
Number of People	8	17	31	64	_	_
Consumption (l/c/d)	70	70	70	70	4850	24667
Calculated Design Volume (m^3)	33	70	126	258	586	1345
Number of Units	14,867	5,591	1,184	182	17	1
Actual Water Harvested	1468950	1182499	451025	142257	19453	4073
Type of Tanks	Ferro-Cement	Ferro-Cement	Ferro-Cement	Brick & Concrete	underground-concrete	underground-concrete
Unit Cost ($/m3)	65	60	55	100	95	90
Cost per Tank	2,145	4,200	6,930	25,800	55,670	121,050
Total Cost US $	31,889,715	23,482,200	8,205,120	4,695,600	946,390	121,050

For scenario 2, the designed volume of the tanks for each type of building has been calculated with the same procedures of that of scenario 1 but taking into account that it is assumed that there is a constant supply of 43 lpcd and only 27 lpcd is from RTRWH (table 4).

Then, the total quantities that could be harvested by implementing all of RTRWH are estimated from 2015 to 2050. It is supposed that RTRWH increases about 2 % annually due to population growth and urbanization, which will both lead to extending the implementation of roof harvesting tanks.

Table 4. The Proposed Rooftop Harvesting Tanks for Scenario 2

TYPE OF BUILDING	Residential				Administrative	Hospital
	A	B	C	D	E	F
Calculated Design Volume (m3)	26	47	100	206	242	1345
Number of Units	14,867	5,591	1,184	182	17	1
Actual Water Harvested	1289326	1030357	397890	126270	13856	4073
Type of Tanks	Ferro-Cement	Ferro-Cement	Ferro-Cement	Brick & Concrete	Brick & Concrete	underground-concrete
Unit Cost ($/m3)	65	60	55	100	95	90
Cost per Tank	1,542	2,559	4,979	20,559	24,182	121,050
Total Cost US $	22,923,979	14,305,090	5,895,340	3,741,767	411,100	121,050

3.5 Water Balance with Harvested Water

In this section, all the expected water harvesting quantities from runoff or rooftops have been gathered and used in the water balance table as a new resource. Then, the amount of water deficit has been calculated; see table 5 (scenarios 1 & 3) and table 6 (scenario 2) that show the water balance.

Table 5. Water Balance with Harvested Water (Scenario no. 1 & 3)

Population	year	2015	2020	2025	2030	2035	2040	2045	2050
	Inhabitant	355138	408316	464229	526772	591357	659332	727956	800575
Total Requirements	m^3/y	10212194	11741356	13349194	15147645	17004825	18959490	20932809	23021021
Water Sold from LC	m^3/y	4082321	4082321	4082321	4082321	4082321	4082321	4082321	4082321
Water from Tankers	m^3/d	8054	9260	10528	11946	13411	14952	16509	18156
	m^3/y	2939665	3379847	3842677	4360376	4894981	5457648	6025684	6626793
Treated Water “drinking”	m^3/d	1611	1852	2106	2389	2682	2990	3302	3631
	m^3/y	587933	675969	768535	872075	978996	1091530	1205137	1325359
Total Water Available	m^3/y	7609919	8138138	8693533	9314772	9956298	10631498	11313142	12034473

Shortage	m³/y	2602275	3603218	4655661	5832873	7048527	8327992	9619668	10986549
	%	25.5%	30.7%	34.9%	38.5%	41.5%	43.9%	46.0%	47.7%
New Water Available (RWH)	m³/y	4150189	4,771,633	5,425,051	6,155,933	6,910,683	7705050	8506998	9355637
Deficit	m³/y	-1,547,914	-1,168,415	-769,390	-323,061	137,844	622,943	1,112,670	1,630,911
	%	-15.2%	-10.0%	-5.8%	-2.1%	0.8%	3.3%	5.3%	7.1%

Table 6. Water Balance with Harvested Water (Scenario no.2)

Population	**Unit**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
	Inhabitant	355138	408316	464229	526772	591357	659332	727956	800575
Total Requirements	m³/d	27979	32168	36573	41500	46589	51944	57350	63071
	m³/y	10212194	11741356	13349194	15147645	17004825	18959490	20932809	23021021
Water Produced	m³/y	5301715	5301715	5301715	5301715	5301715	5301715	5301715	5301715
Losses	%	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00
	m³/y	1219394	1219394	1219394	1219394	1219394	1219394	1219394	1219394
Water Sold from LC	m³/y	4082321	4082321	4082321	4082321	4082321	4082321	4082321	4082321
Water from Tankers	m³/d	8054	9260	10528	11946	13411	14952	16509	18156
	m³/y	2939665	3379847	3842677	4360376	4894981	5457648	6025684	6626793
Treated Water "drinking"	m³/d	1611	1852	2106	2389	2682	2990	3302	3631
	m³/y	587933	675969	768535	872075	978996	1091530	1205137	1325359
Total Water Available	m³/y	7609919	8138137	8693533	9314772	9956298	10631498	11313141	12034473
Shortage	m³/y	-2602275	-3603218	-4655661	-5832873	-7048528	-8327992	-9619668	-10986549
	%	25%	31%	35%	39%	41%	44%	46%	48%
New Water Available	m³/y	3634015	4,178,168	4,750,318	5,390,297	6,051,176	6746744	7448951	8192042
Deficit	m³/y	-1,031,739	-574,949	-94,656	442,576	997,352	1,581,248	2,170,717	2,794,507
	%	-10%	-5%	-1%	3%	6%	8%	10%	12%

4 ECONOMIC ASSESSMENT OF RWH

In the previous section, cost calculations and estimations of the project were conducted. This section provides the results of the economic assessment. There are many social benefits expected to be gained from constructing a given WH project, all of which do not have direct market values. The estimated project life span is 35 years (2015-2050), beginning with year (2015), which is the base year when the investment occurs and continues through year (2015) when the benefit stream appears after construction and therefore continues to the end of the project. The main cost categories are distinguished as initial investments (capital cost) and operations and maintenance (running cost). The capital cost of the project was presented in the previous section. The total operational cost includes the cost of raw materials such as chemicals, cost of utilities requirements such as (energy, fuel, wages of direct labor and administration cost, as well as maintenance cost). It is estimated around 4 % out of the total investment cost. The investment cost as well as the operational cost and their disbursements during the life span for all scenarios were calculated. The annual increase in costs appears due to the expected extension of implementation in rooftop harvesting tanks as it is estimated to increase due to annual population growth and urbanization. It should be noted that the first and third scenarios have the same cost. In the economic analysis of the project, all prices, costs and returns which were estimated or valued in the Yemeni currency (Rial) were converted to US dollar, using the exchange rate of 214.8 RY/US $ in December 2014. The total cash outflow is estimated to be 91.6 million US $ for scenarios 1 and 3 in 2015 decreased to 3.9 million US $ in 2050. For scenario 2, the total cash outflow is estimated to be 67.7 million US $ in 2015 and decreased to 2.9 million US $ in 2050

Since the inhabitants of Ibb City are spending more than 15% of their monthly income for purchasing water from private venders “Tankers”. The average price of water from private vendors is estimated at Rial Yemeni (RY) 1500 per cubic meter. Therefore, by carrying out RWH techniques project it is expected that the purchases of tankers will eventually decrease. The future water available as the expected result of the current study project is multiplied by the willingness to pay and 100 % out of this water is expected to be used instead of tankers, which represents the change in willingness to pay. The change in willingness to pay for water is considered one of the project's indirect benefits. The economic benefits of reduction in tanker purchases is estimated to be about 20.5 million US $ in 2015 and increased to 46.3 million US $ in 2050.

Inhabitants in Ibb City are mainly depending on bottled water for drinking purpose. 60 % of inhabitants spend more than 11 % of their monthly income on bottled water. Therefore, it was assumed that the reduction in bottled water purchases will approximately equal 100 % as a result of using harvested water. The reduction in household expenditure in bottled water is another indirect benefit of the project. The economic benefits of reduction in the Purchases of bottled water is estimated to be about 19.2 million US $ in 2015 reaching 43.2 million US $ in 2050.

Population of Ibb city depend fully on the water provided by the LC and monthly spend about 9% of their income for water. Water harvesting is the best solution to reduce the cost based on the suggested scenarios. The rate of benefits and the return differs from different scenarios as the amount of saved water differs. For scenario 1, total reduction on LC water expenses is estimated to be about 0.8 million US $ in 2015 and reaching 1.9 million US $ in 2050. For scenario 2, total reduction on LC water expenses is estimated to be about 0.20 million US $ in 2015 and reaching 0.46 million US $ in 2050. Whereas for scenario 3, total reduction on LC water expenses is estimated to be about 0.13 million US $ per year within the project lifetime. Table 7 illustrates total cash inflows (saved cash), cash outflows (cost) and net cash flows. The operational costs increase as a result of both the increasing production capacity of the project, and the increase coverage percentage.

Table 7. The Economic Cash flows in million US $ of RTRWH in Ibb City

Scenario	Scenario 1			Scenario 2			Scenario 3		
Years	Total Inflow (saved cash)	Total outflow (cost)	Total Net Cash Flows	Total Inflow (saved cash)	Total outflow (cost)	Total Net Cash Flows	Total Inflow (saved cash)	Total outflow (cost)	Total Net Cash Flows
2015	40.512	91.573	-51.060	39.891	67.617	-27.726	52.715	91.573	-38.859
2020	46.602	2.897	43.705	45.864	2.140	43.724	58.647	2.898	55.749

2025	52.985	3.033	49.951	52.144	2.240	49.905	64.896	3.033	61.862
2030	60.123	3.390	56.732	59.170	2.503	56.666	71.885	3.390	68.495
2035	67.494	3.487	64.008	66.424	2.574	63.850	79.103	3.487	75.616
2040	75.253	3.660	71.592	74.059	2.702	71.357	86.699	3.660	83.039
2045	83.085	3.681	79.404	81.768	2.717	79.050	94.368	3.681	90.688
2050	91.373	3.889	87.484	89.925	2.871	87.053	102	3.889	98.595

To evaluate the project in terms of its economic feasibility, two evaluation methods of measures namely; discounted measures and undiscounted measures are used. The discounted measures include the Economic Internal Rate of Return (EIRR), the Net Present Value (NPV), the Benefit/Cost (B/C) ratio and the total cost of producing one unit (Average Incremental Cost) (E-AIC), while the undiscounted measure is namely the payback period of the project.

The economic feasibility study shows that the project is economically feasible as NPV equals to 714, 711, and 956 million US$ for the three scenarios respectively. The economic feasibility study shows that the project of water harvesting is economically feasible; as the EIRR of the project is 84, 144 and 142 % for three scenarios, respectively. The economic B/C ratio of the proposed project at 6 % discount ranges from 6.7 (scenario 1) up to 8.6 (scenarios 2 & 3). This indicates that the project is economically viable. The E-AIC is an indicator of the full cost recovery which shows the cost per one cubic meter. The economic E-AIC of water harvesting project in Ibb is 1.75 US$/m^3 in scenario no 3 at a discount rate of 6 %. The payback period is the length of time from the beginning of the project, until the net value of cash flow reaches the total amount of the capital investment. The payback period of the proposed project is about 2 years in the current economic analysis.

5 SENSITIVITY ANALYSIS

Since the estimated cost and benefits have different assumptions, the sensitivity analysis has been conducted to show to what extent the project can accommodate variations in possible outcomes. Tables 8.-10 illustrate these possible outcomes of the analysis carried out including: increasing investment cost by 10 %, increasing operation costs by 10 %, increasing the total cost by 10 %, decreasing total benefit 10 %, and increasing the total cost and total benefit by 10 % simultaneously. The results indicate that the project can tolerate risks associated with variations in the expected inputs and outcomes.

Table 8. Results of Sensitivity Analysis of Economic Feasibility Scenario 1

Indicators	Discounted measures				Undiscounted measures
	IRR	B/C	NPV	AIC	PAYBACK
Basic	84%	6.55	714,002,909	1.76	2.20
Increasing Investment Cost (10%)	71%	5.96	701,140,755	1.93	2.42
Increasing Operational Cost (10%)	83%	6.53	713,508,211	1.80	2.20
Increasing Total Cost (10%)	70%	5.93	700,596,587	1.98	2.42
Decreasing Total Benefits (10%)	69%	5.90	629,740,464	1.76	2.44
Increasing Total Cost and Decreasing Benefits	59%	5.34	616,334,141	1.98	2.69

Table 9. Results of Sensitivity Analysis of Economic Feasibility Scenario 2

Indicators	Discounted measures				Undiscounted measures
	IRR	B/C	NPV	AIC	PAYBACK
Basic	144%	8.49	710,925,039	1.85	1.70
Increasing Investment Cost (10%)	116%	7.71	701,427,736	2.10	1.86
Increasing Operational Cost (10%)	143%	8.45	710,559,759	1.98	1.70
Increasing Total Cost (10%)	115%	7.68	701,025,927	2.18	1.87
Decreasing Total Benefits (10%)	113%	7.64	630,335,232	1.91	1.88
Increasing Total Cost and Decreasing Benefits	93%	6.92	620,436,120	2.18	2.08

Table 10. Results of Sensitivity Analysis of Economic Feasibility Scenario 3

Indicators	Discounted measures				Undiscounted measures
	IRR	B/C	NPV	AIC	PAYBACK
Basic	142%	8.43	955,988,110	1.70	1.71
Increasing Investment Cost (10%)	114%	7.67	943,125,956	1.93	1.88
Increasing Operational Cost (10%)	140%	8.40	955,493,412	1.80	1.71
Increasing Total Cost (10%)	113%	7.64	942,581,787	1.98	1.88
Decreasing Total Benefits (10%)	112%	7.59	847,527,145	1.76	1.90
Increasing Total Cost and Decreasing Benefits	92%	6.87	834,120,822	1.98	2.09

CONCLUSION

This research focuses on detailed study for collecting harvesting water and found that roof top water is the best available solution to cope with increasing water demands of Ibb.

It was found that the main resource of water represented by the public institution of drinking water and sewage covers only 72% of the population in the year 2015 at about 43 liter /person /day. Besides, it addresses the problem of the increasing number of wells that usually stop working due to continuous and rapid decline of the groundwater table by about 6 m/year and deterioration of the quality of water.

The quality of rainwater was evaluated and compared by the standards of the international health organization and the Yemeni law of water and found that harvested rainwater is satisfactory if the main treatments were carefully followed. These treatments are represented by cleaning the roofs and first flushing, besides using the silver filter that has proofed its effectiveness in previous experiments. It is also found that the harvested water was found to be of higher quality when compared with the main water supply.

The analysis found that the shortage at study area is about 25 % for the year 2015 and will continue increasing to reach 48% by the year 2050.

Three Scenarios were assumed for the determination of harvested water. The first scenario is to fully utilize the harvested water which was found to represent 48.6% from the demanded water according to the international health organization which is 34 lpcd. The total amount of harvested water is 4.413 Mm^3/year (2015) which will reach 9.340 Mm^3 by the year 2050 with increasing the number of population and area of buildings top roofs. These quantities will eliminate or reduce the shortage and save about 15.1% from water of 2015 to reach 0% by 2034. Finally, a shortage will emerge again to become 7.2 % which is relatively small compared to the 48% of shortage without harvesting.

The second scenario is to utilize the local supplied water by the institution of water and sewage as a main resource to cover 43 liter/person/day plus 27 liter/person/day from RWH to achieve 36% of the water needed .The total harvested water for 2015 will become 3.634 Mm^3/year and then finally reach 8.192 Mm^3/year by the year 2050. Therefore, The shortage will be reduced from 25% before the harvesting to surplus of 10% in the early years to become 0% in 2026 and the shortage becomes 12.2 % instead of 28% at the same year without harvesting.

The third scenario is very close to the current situation of Yemen and is the expected future, especially with more war and threats of drought and lack of fuel. In summary, this scenario is the case of rain water harvesting only and adopting it so that the consumption per person becomes 34 liters/day.

From the previous scenarios, the size of tanks for harvested water were determined and the type and location of construction according to the roof area and the demand of the users. This was done with lowest cost.

The economic study has shown that rainwater harvesting is more effective than other resources. This system is independent from any control and the person can directly obtain his amount of harvested rainwater to his own tank. Besides, the low cost in the long term by comparing the three scenarios, it was found that the first scenario obtained value of EIRR equal to 97% compared to 85% and 75% for scenarios 2 and 3, respectively. Using other index like NPV was found to be highest in the second scenario at 850 million USD compared to 760 and 680 million USD for scenarios 1 and 3, respectively. The profit rate index of the cost is 6 in the first scenario where in scenarios 2 and 3 it is 7 and 8, respectively. E-AIC index is found to have the lowest price in the third scenario at 1.70 USD/m^3 whereas in the second scenario it is 1.91 USD/m^3. The calculation of payback indicated that the third scenario needed 1.71 years for the capital investment recovery compared to 2.2 years and 1.7 years for the first and second scenarios, respectively.

RECOMMENDATIONS

1. It is preferred to have a special code for Yemen that contains all cities to be a reference for rain water harvesting. The code should contain all the required information such as deciding the type and size of tanks, tanks construction equipment, and its steps.
2. Conducting the water quality analysis of rainwater after being stored for long periods to analyze the effects of type of tank on the water quality especially biologically.
3. Studying other possible techniques in harvesting rainwater system from streets and gardens and highlighting their usage.
4. The use of models and GIS and spatial information to choose the right places to harvest water, especially rain water to be meaningful and useful
5. Extending this study to cover the maximum possible area which are close to Ibb City especially the villages.
6. EIA should be conducted for the proposed system, to ensure the sustainability of the environment.
7. Raising public awareness regarding the effect of disposal of solid and liquid waste on surface and ground water quality. Moreover, raising the awareness of the importance of water harvesting and the types of low cost methods.

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