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THE EFFICIENCY OF RAINWATER HARVESTING SYSTEMS IN THE LEBANESE COASTAL ZONE

Kareem Galal
Associate Professor, Faculty of Science, Beirut Arab University, Design & Built Environment, Tripoli, Lebanon, kareem.jalal@bau.edu.lb

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Abstract

Water conservation is one of the most important trends within sustainable applications in the world today. The global fresh water demand has increased by 1% per year since the 1980s, and it is estimated that it will continue increasing at this rate until 2050. Therefore, utilizing the available rain water has become a vital parameter for most of the world's countries that lie within the water demand red-zone. Lebanon is moving toward the water demand red-zone rapidly, which has prompted the consideration of rain water harvesting (RWH) systems in the last ten years. The variety in precipitation in the different Lebanese climatic zones has made it essential to examine the efficiency of this project in the Coastal Zone in comparison with the actual water demand. This research focuses on (RWH) and the low-requirements of the water filtering process, such as flushing and irrigation water to reduce the effects of the quality and economic factors. The theoretical approach and experimental case studies were applied to obtain a tangible result regarding RWH efficiency in this Lebanese climatic zone. The research determines estimated values for the RWH volume rate per unit area and for each mm of the annual rainfall average, in addition to the area that could be irrigated for each mm of the annual rainfall average per unit area of the catchment surface. The research also determines the aspects that affect the RWH systems efficiency generally and in Lebanese Costal zone specifically. The economical aspects tackled in the research help to estimate approximate cost for RWH overall systems or specific components of RWH systems in Lebanon, which lead to calculate the payback factor of the investment.

Keywords

Rain Water Harvesting - Lebanese Coastal Zone - Rainfall - Water demand - Precipitation

1. INTRODUCTION:

According to the world population clock, the total world population is currently around 7.7 billion (World meters, 2019), around 26% of which lives in countries experiencing high water stress, and about 52% experience severe water scarcity during at least one month of the year. Global water demand is expected to increase at 1% rate per year until 2030 (about a 20-30% total increase), which will place greater stress on the global water resources, leading to increased water scarcity and a stronger intention to activate water sustainable plans, such as Rain Water Harvesting (RWH) (UN, 2019c). Many studies and projects have been applied globally to save rainwater, one of which is the United Nations Environment support to a project for harvesting rainwater for agricultural use in South Africa (UN, 2019a). Another example is the United Nations program of Global Rain Water Harvesting Collective (GRWHC) that tends to apply its projects in many developing countries around the world such as Ethiopia, India, Nepal, and Senegal. It works on providing drinking water to schools facing an acute shortage in water through roof top rain water harvesting system in schools (UN, 2019b). In Lebanon, the estimated available renewable freshwater resources for an average rainy year is 4,100 MCM. Based on the United Nations Environment Program (UNEP) water scarcity threshold of 1,000 m^3/capita/year, Lebanon is clearly approaching the red-zone as far as fresh water resources are concerned, with an estimated 30% increase in population size in the next 20 years. The precipitation rates vary between the four Lebanese climatic zones. The Mountain zones (High and Western Mid) have the highest precipitation, while the Coastal zone is in the middle, and the Inland Plateau zone has the least. The precipitation rate has dropped by 8% in the Beirut and Tripoli areas in the last 30 years; therefore, the available renewable freshwater resources in the Coastal zone have decreased (Al-Housseiny, 2016). This have led many people - especially from the Mountain climatic zones – to collect rainwater, though they are using traditional age old methods such as using open tanks. Collected water is mainly used to cover irrigation needs with around 400 liter/day tanks. Moreover, some residential buildings in the Coastal zone have turned to utilizing the rainfall resource by incorporating RWH systems into them due to suffering from the salted water wells at the end of August during drought years, especially that the Coastal zone contains the highest proportion of urban growth, with 60% of residential buildings within its total built area.

2. RESEARCH AIM AND METHODOLOGY:

The research is divided into two sections; the first is a theoretical approach which ends up with a theoretical model and the second is an experimental approach to examine some aspects of the theoretical model in the Lebanese Coastal zone context. The theoretical approach determines the aspects that affect the RWHS efficiency in general and focuses specifically on the Lebanese Costal zone. The study starts with the macro level of the Coastal zone's precipitation characteristics, water demands, and the RWH potentials. It then identifies the rainwater harvesting methods according to different classification systems. Theses systems could be applied to the Lebanese Coastal zone. After that the research discusses the systems requirements for macro and micro scales, as well as the economical aspects that help to estimate the approximate cost for RWH systems in Lebanon in order to calculate the payback factor of the investment. The experimental part aims to examine the efficiency of using RWH systems in the Lebanese Coastal zone to cover in a simple way the water needs for public buildings. It applies the capacity / economical aspects and RWHS requirements on two case studies located in the low and high altitude levels of the Lebanese Coastal zone. It then calculates the potential RWH volume from the buildings and outdoor areas, and the possibility of fulfilling the water demand for certain activities that do not require a complicated filtering process, such as flushing and irrigation, to reduce the economical factor and catchment area requirements effects. The research also aims to determine estimated values for the RWH volume rate per unit area and for each mm of the annual rainfall average, in addition to the area that could be irrigated for each mm of the annual rainfall average per unit area of the catchment surface. The experimental study also examines the payback period of the total cost for the RWH investment to test the economical efficiency of the RWHS in the Lebanese Coastal zone.

3. PRECIPITATION CHARACTERISTICS of THE LEBANESE COASTAL ZONE:

According to (MPWT/DGU and UNDP/GEF, 2005), the Lebanese climatic zones are classified into four climatic zones: 1- Coastal, 2- Western Mid-Mountain, 3- Inland Plateau and 4- High Mountain. The Coastal climatic zone is located between the seashore and the western mountain (0-700m altitude) (see figure 1). Lebanon's most important cities are located in this zone (Beirut, Tripoli, Saida, Tyr, Jbeil, etc.). It contains the highest proportion of urban growth and population (around 46.75% of Lebanon's population) (see table 1) (Traboulsi & Traboulsi, 2017) (Ministry of Energy and Water, 2010). The population density of the coastal zone is the highest (1588 P/Km²) (Al-Housseiny, 2016).

The precipitation level of the Coastal zone varies from 740 to 960 mm/year (see table 1), giving an average of 827.78 mm/year. It also has the second highest precipitation, of around 1000 mm/year in the central region, 900 mm/year in the north, and 700 mm/year in the south, giving an average of 866.67 mm/year overall (MPWT/DGU and UNDP/GEF, 2005).

The period from November to March (5 months) constitutes the highest precipitation level (around 85%); this period is the most important for RWH storage capacity planning (see figure 2).

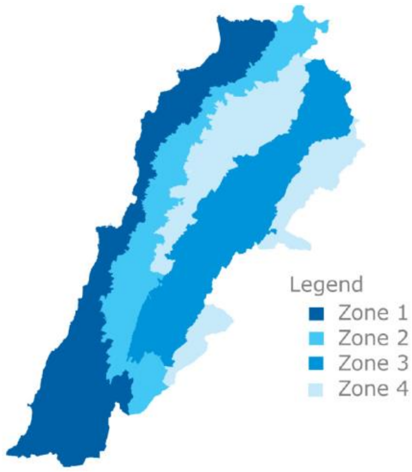

Figure 1: The Lebanese Climatic Zones published in 2005 under the Project capacity building for the adaption and application of thermal standards for buildings. (MPWT/DGU and UNDP/GEF, 2005)

Table 1 Average precipitation in Lebanon, according to different sources: A: (Traboulsi & Traboulsi, 2017) (Ministry of Energy and Water, 2010), B: (National & Ministry, 2011), and C: (Al-Housseiny, 2016)

		(Source A)				(Source B)				(Source C)		
		Governorate	Rainfall (mm/year) Region	Rainfall (mm/year) Zone Avg.	Population (million)	Governorate	Rainfall (mm/year) Region	Rainfall (mm/year) Zone Avg.	No. of Stations	Region	Rainfall (mm/year) Region	Rainfall (mm/year) Zone Avg.
Mount Lebanon	Western Mid-Mountain	Mount Lebanon	1200	**1200**	1.977	Mount-Lebanon	1210	**1210**	36	Western Slopes of Mount Lebanon Range 500 – 1200 m	1200	**1150**
	High Mountain									Western Slopes of Mount Lebanon Range 1200 – 1800 m	1100	
Coastal		North	1000	**783.33**	0.964	North	1055	**960**	25	Littoral North up to 500 m altitude	745	**740**
		Beirut	600		0.46	Beirut	892		4	Littoral Center up to 500 m altitude	850	
										Beirut	710	
		South	750		0.82	South	933		26	Littoral South up to 500 m altitude	655	
Inland Plateau		Beqaa	600	**600**	0.579	Beqaa	705	**705**	36	Bekaa North	450	**670**
										Bekaa Center	690	
										Bekaa South	870	
Total		------	**4150**	**861.11**	**4.8**	------	**4796**	**958.33**	**127**	------	**7270**	**853**

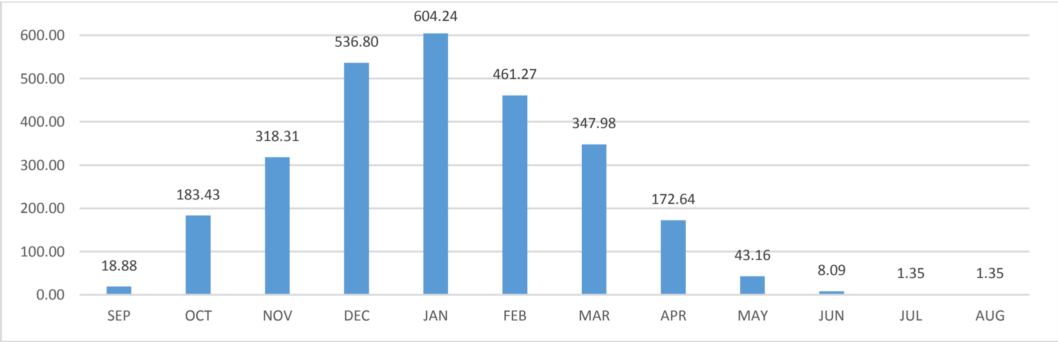

Figure 2: Average precipitation in Lebanon along the year (mm/year), (Al-Housseiny, 2016)
Source: Author

Lebanon's estimated water demand for 2020 is 1483 MCM and 1802 MCM for 2035 (see table 2); thus, the water demand in the Coastal zone may be around 693.3 MCM in 2020 and 842.9 MCM in 2035 according to the population percentage of the climatic zone.

Table 2 The MCM (million cubic meters) estimated annual water demand by sector (2010–2035) (Traboulsi & Traboulsi, 2017)

Sector	2010	2015	2020	2025	2030	2035
Domestic	505	460	427	467	512	562
Industrial	152	138	128	140	154	169
Tourism	6	8	10	13	16	21
Irrigation	810	877	935	983	1021	1050
Total	1473	1483	1500	1603	1703	1802

The watercourses in Lebanon provided the country with 3400 MCM in 2006, with around 1515 MCM in the Coastal zone, and about a 21% discharge into the sea. The underground water is estimated to be around 700 MCM, with more than 45,000 private wells in 2005, which become salted annually, at the end of August, due to the main dependence of the domestic sector on wells to fulfill the water demand (National & Ministry, 2011). The water reservation in Lebanon is sufficient for this period, but the sustainable factor guides us to utilize different resources for future generations, especially for the domestic sector. Since 60% of the population in the Coastal zone lives in multi-story buildings which depend mainly on underground water resources, this leads to water scarcity at the end of August in years of drought. The potential of RWH in Lebanon is estimated to be 23.418 MCM and 9 MCM in the Coastal zone, assuming that 80% of the runoff area is available (runoff coefficient) and that 50% of the rain water from the total area is harvested (Traboulsi & Traboulsi, 2017).

4. THE RAINWATER HARVISTING METHODS:

According to (Kumar, 2006), there exist two RWH methods, based on the time of usage: Storing rain water for direct use (see figure 3); that is suitable for domestic or small public buildings use. Recharging ground water aquafers, from roof top run-off or from the ground area (see figures 4 and 5); that is suitable for the large scale projects. Another classification based on these uses can be determined by employing two methods (see figure 6): Domestic and small-scale irrigation (Micro Catchments), based on roof catchment systems and small surface catchment.

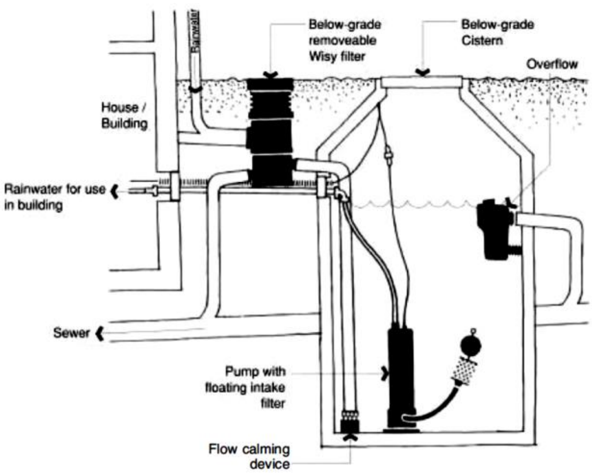

Figure 3: Storing rain water for direct use (Kinkade-Levario, 2007)

Productive purposes (Macro Catchments), based on small-scale dams, and external catchment run-off diverted into fields. The national guidelines for the RWH systems (Al-Housseiny, 2016) classify water use into four categories, which can be summarized as two main types:

- Potable use: Drinking, cooking…etc.
- Non-potable use: Suitable for human contact except for drinking and cooking.
- Preferably no human contact.
- Not suitable for human contact.

From these classifications, the process of RWH may be as follows (Kinkade-Levario, 2007):

- Catchment area determination (rooftop, solid surface pavement/parking, rock surface, open field, etc.).
- Discharging pollution if possible.
- Storage determination (Domestic use cistern, natural rocky underground or surface cistern, etc.).
- Storage connection with an over-flow system and an alternate water supply source, especially for the domestic system.
- Supporting the system with purification tools (filters) for potable use.

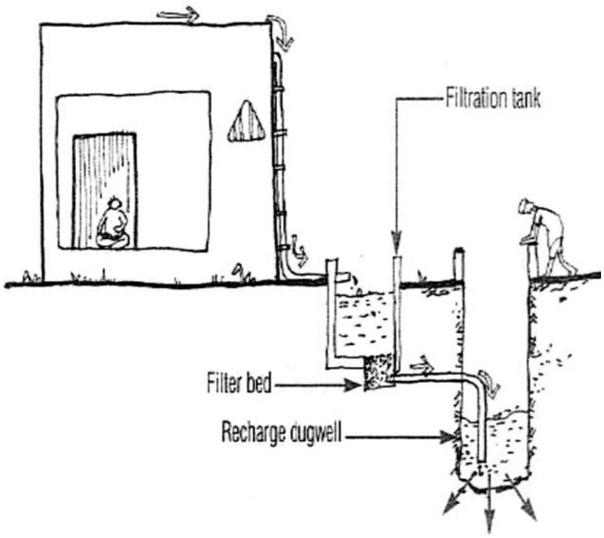

Figure 4: Recharging ground water aquifers, from roof top run off (Kumar, 2006)

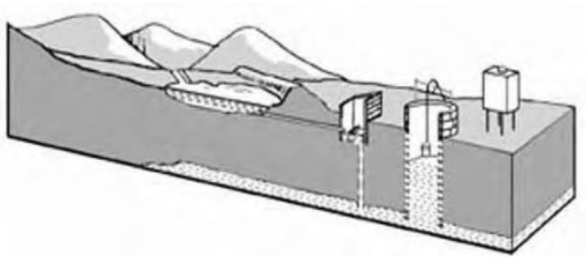
Figure 5: Recharging ground water aquifers (well), from ground area (Sawicki, 2009)

The characteristics of the Lebanese Coastal zone allow to use any types of the above methods according to the scale and the purpose of water uses. There are actual projects executed at micro level for residential buildings for example in Beirut City (Coast), Aramon and Bchamoun districts (about 550 m altitude), and at macro level such as Anan Lake (620 m Altitude) that stores 35 MCM of water.

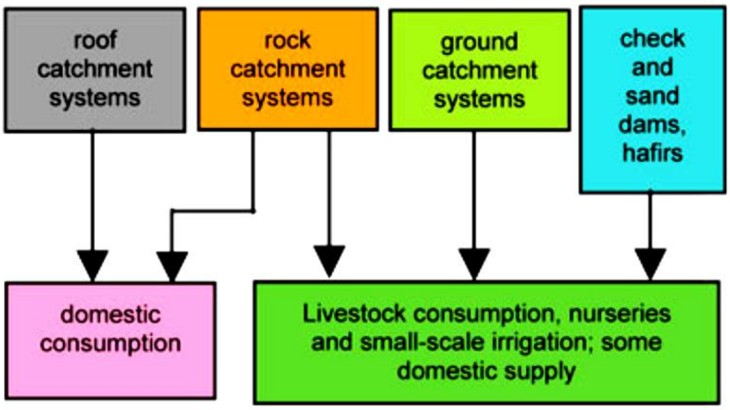

Figure 6: Small scale (RWH) classification and uses (Khoury-Nolde, 2008)

5. RAINWATER HARVESTING REQUIREMENTS AND ECONOMICS:

There are several requirements that should be taken into consideration with regard to RWH systems, depending on the size of the project. For large-scale projects (city projects, for example), the conditions are classified into three categories: Physical, Social, and Technical, each of which is further divided into three sub-categories (see figure 7). This study has been stablished mainly for developing countries, placing the social factor on the second level of importance, to ensure that society will accept and interact with the project (Milagros, 2007).

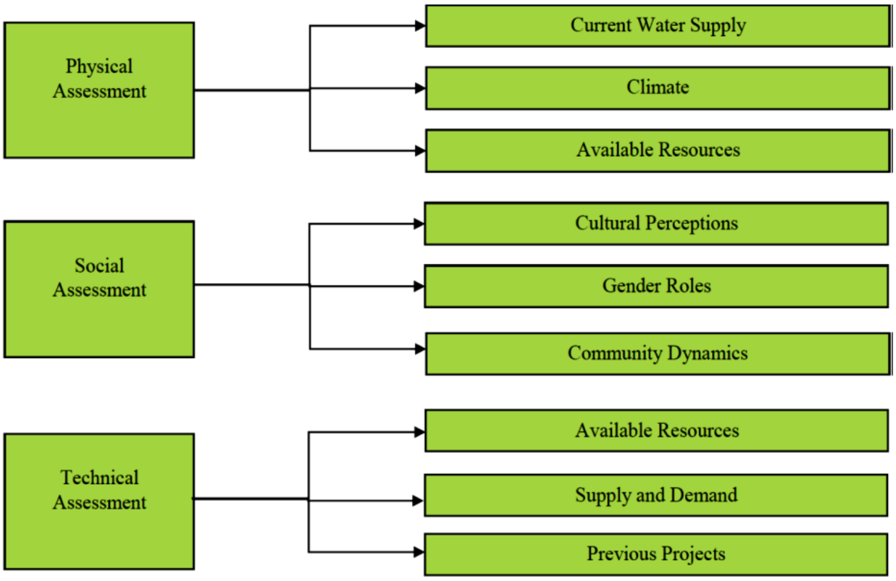

Figure 7: RWH requirements for big scale projects (Milagros, 2007)

The main requirements of the micro scale and certain macro scale projects are based on physical, technical, and economic factors. The requirements vary according to the quality of the harvested water, and can be classified into four categories, from the highest quality to the lowest (see table 3).

Table 3: RWH matrix requirements for micro and macro scale projects classified into four categories form highest quality (Level-01) to lowest (Level-04) (Al-Housseiny, 2016)

Requirements	**Level -01**	**Level -02**	**Level -03**	**Level -04**
- Collection surface is not used for plantations of any kind and has no soil layer.	X	X	X	X
- (RWH) system has a first flush tank in good working order.	X	X	X	--
- Collection surface and drainage equipment are not made of asbestos, copper, lead or zinc, and not used as a driveway.	X	X	X	--
- Collection area is not accessible for continuous human circulation, occupancy or use for solar water heating, photovoltaic, ventilation fans, AC condensing units or any sort of equipment and planters.	X	X	--	--
- Far at least 3 km away from any industrial plant that has smokestacks and 1500 m away from a hospital that incinerates its medical waste.	X	--	--	--
- Located in a village or an area that is sparsely populated.	X	--	--	--
- Lowest point of collection surface is at least 3 m above ground level.	X	--	--	--
- Collection area has no exhaust outlets like kitchen exhaust, chimney outlet, boiler outlet, etc. that are at less than 2 m height from collection surface.	X	--	--	--
- No overhanging trees above Collection surface.	X	--	--	--
- Trees having a crown above the collection surface should be at least 3meters away.	X	--	--	--
- (RW) storage tank should have food grade interior finish. For plastic or fiberglass tanks, food grade labeling should be specified by the tank manufacturer, for built on site concrete tanks, food grade is determined by the type of surface coating which should be specified food grade by the coating manufacturer.	X	--	--	--

There are also economic requirements. The potential RWH amount is estimated using the following equation (Traboulsi & Traboulsi, 2017):

$$(\text{RWH})\ (\mathbf{M^3}) = \text{R}\ (\mathbf{MM/YEAR}) * \text{A}\ (\mathbf{M}) * \text{K}$$

R: The average rainfall in the area.
A: The total catchment area.
K: The runoff coefficient.

The catchment areas for the micro or macro scale projects vary. These may be rooftops for houses or public buildings, green houses, courtyards, roads, parking areas, playgrounds, etc. The high runoff coefficient varies from 50-90% (70-80% for rooftops due to leakage and evaporation) (see table 4). The evaporation rate of Lebanon is estimated to be 50% of the annual precipitation volume (Farhat, 2018). The high evaporation rate in Lebanon is due to lack of water sustainability plans, where a large amount of rainwater is spread along the earth surface or collected in artificial lakes (uncovered collection basins). This method of calculation is changed regarding RWH for farms; the Catchment to Cropping Area Ratio (CCR) will be assumed to be from 1:1 to 10:1, according to the soil characteristics for catchment and cropping conditions (with certain poor soil characteristics, it can be as high as 100:1) (Prinz, 2011).

Table 4: Runoff coefficient according to the land use and soil type (Californian Environmental Protection Agency, 2016)

Land Use	Runoff coefficient	Land Use	Runoff coefficient
Streets:		**Lawns:**	
Asphaltic	0.70 - 0.95	Sandy soil, flat, 2%	0.05 - 0.10
Concrete	0.80 - 0.95	Sandy soil, avg., 2-7%	0.10 - 0.15
Brick	0.70 - 0.85	Sandy soil, steep, 7%	0.15 - 0.20
		Heavy soil, flat, 2%	0.13 - 0.17
Roofs	0.75 - 0.95	Heavy soil, avg., 2-7%	0.18 - 0.22
Playgrounds	0.20 - 0.35	Heavy soil, steep, 7%	0.25 - 0.35

The estimated cost of the RWHS depends on the following parameters (Ponces, 2015) (Rahman, Dbais, Imteaz, Bag, & Dc, 2010):

Investment/Capital costs.

Operation, replacement and maintenance costs.

Water price.

Payback period.

The Capital/Investment cost of the RWHS that is designed for flushing and non-potable uses is considered as the highest ratio of the RWHS cost (67.86%), followed by the maintenance ratio (18.40%), then the lowest ratio goes for the replacement and operation costs (13.74%) (see figure 8). The large amount of the Capital cost makes it the key player in the RWHS. The plumbing-labor cost forms the highest ratio in the Capital cost (64.28%) followed by tank and concrete costs (24.21%); while the Pumps, Accessories and Electrician costs are the lowest ratio (11.51%) (see figure 8).

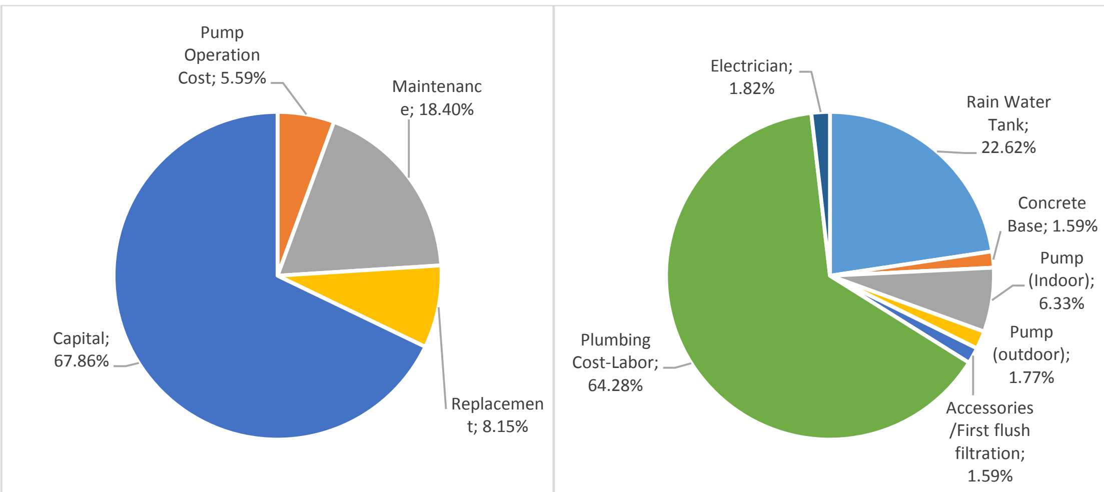

Figure 8: The total RWHS contents estimated cost ratios (in the left), and the Capital cost contents ratio for the RWHS project designed for flushing and non-drinking/cooking uses (in the right) (Rahman et al., 2010)

For projects executed in Lebanon (July 2014) (Al-Housseiny, 2016), the average Tank cost was 0.55 \$/L. The Plumbing cost is divided into three contents: Drains 80\$/ m2, Gutters/Downspouts 7.25\$/m, and Piping 4.29\$/m. The Pumps costs are: 193.04\$/(m3/h) for horizontal installations, 368.7\$/(m3/h) for vertical installations, and 587\$/(m3/h) for submersible.

The average ratio of the RWHS cost to the storage capacity is 0.41 $/L according to previous projects executed in Lebanon in 2013-2014. This value raises to 0.46 $/L according to the Consumer Price Index (CPI) (10%) from 2013-2019, while the cost ratio to the Catchment Area (CA) is 47.69 $/m2 with the 10% CPI (see table 5).

Table 5 Three RWHS projects costs executed in Lebanon (2013-2014) and the modification of the cost ratios according to (CPI) from 2013-2019 (Al-Housseiny, 2016) (Trading Economics, 2019) (Source: Author)

	Catchment Area (CA)	Tank size	Cost all	Uses	Cost : Storage Capacity	Cost : Storage Capacity with 2019 CPI	Cost : CA	Cost : CA with 2019 CPI
	m^2	L	$		$/L	$/L	$\$/m^2$	$\$/m^2$
Project-01	690	44000	15000	Flushing	0.34	0.38	21.74	23.91
Project-02	300	44000	25000	Flushing	0.57	0.63	83.33	91.67
Project-03	400	30000	10000	Flushing	0.33	0.37	25.00	27.50
Average					**0.41**	**0.46**	**43.36**	**47.69**

Form the above economical analysis, the RWH project cost could be estimated in order to be compared with the water price for non potable uses in the Coastal zone to calculate the payback period of the RWH project.

6. CASE STUDY:

The following points will present the case study as follows:

6.1 Introduction:

The case studies are Beirut Arab University (BAU) Debbieh (Case-A) and Tripoli (Case-B) Campuses. They are both considered within the Coastal Zone of Lebanon, though Case-A is on the periphery of the Coastal Zone near the Western Mid-Mountain zone, and Case-B is next to the shore. These two locations in different altitude levels examine the highest and lowest amount of the RWH volume in this climatic zone.

- Case-A is located in the Debbieh region. The entrance coordinates are 33°40'34.62"N, 35°28'04.37"E and 398m elevation; the lowest point in the site is in the west valley 33°40'19.21"N, 35°27'06.38"E and 181m elevation; and the mean level of the built area is 364.5m. The total site area is 1381808.86m2. It contains four main buildings, four dorm buildings, service buildings, sports fields, etc. (see figure 9, and table 6). The site also contains an under construction (RWH) artificial lake (collection basin) 33°40'30.89"N, 35°27'40.85"E and 331m elevation, at the lowest point of the main built area.
- Case-B is located in Tripoli city; the main elevation of the site is located on the Tripoli Corniche Road in El-Mina district. The entrance coordinates are 34°25'55.98"N, 35°48'50.11"E and 1.0 m elevation. The total site area is 15840m2; the mean level is flat and contains faculties, administration buildings, and sports fields (see figure 10, and table 6).

The average rainfall for the study areas, according to (Al-Housseiny, 2016), is 975 mm/year for the Debbieh region, and 745 mm/year for the El-Mina Tripoli region. The average measured by the BAU weather stations for the two campuses are 1131 mm/year for the Debbieh Campus (Case-A) and 821 mm/year for the Tripoli Campus (Case-B). These readings were collected from 23-10-2015 to 22-10-2016 for (Case-A) and from 18-09-2015 to 17-09-2016 for (Case-B) (BAU Weather Stations, 2016). The study calculates the RWH volume (**M**3) using the rainfall averages provided by the BAU weather stations and the rainfall annual average of the Debbieh and El Mina districts. The runoff coefficient is assumed to be: (0.7) for buildings` roofs (the rooftop finishing type used in most of the buildings is loose tile type), (0.8) for asphalt roads and pavements, (0.3) for sports fields, and (0.2) for green and sandy areas (Lawns) which are studied in Case-B only where the surfaces are flat (see table 4). Then it calculates the RWH volume monthly according to the annual rainfall average, and during the five effective months (November - March) (see table 7).

Table 6 BAU Debbieh Campus (Case A) and Tripoli Campus (Case B) roof top areas and contents (numbers refer to the site map contents, see figures 9 and 10) (D.P.L.G, 2019) (Source: Author)

Debbieh Campus (Case A)					
#	**Contents**	**Area (m^2)**	**#**	**Contents**	**Area (m^2)**
1	Architecture Building	4365	**12**	Astronomical Observatory Dome	20
2	Engineering & Science Bldg.	3350	**13**	Astronomy piazza	60
3	Laboratories Building	1660	**14**	Sport hall	3000
4	A4 Building	5200	**15**	Main Sports Field-Track	15160
5	4 Dorm Buildings	2160	**16**	Small Sports Fields	2950
6	Mosque	630	**17**	Main Amphitheater	6800
7	Mosque piazza	750	**18**	Secondary Amphitheater A4 Building	6630
8	Cafeteria	150	**19**	Lake (Under construction)	2950
9	Social Building	520	**20**	Lake`s Pavement (Under construction)	4620
10	Social Building Piazza	525	**21**	Roads, sidewalks, and Roundabouts	96600
11	Service Buildings	530	**22**	Parking Lots	14200
Total site contents and Roof Top area					**172830**
Total site Area					**1381809**
Tripoli Campus (Case B)					
1	Building -A	650	**6**	Building -F	720
2	Building -B	2600	**7**	Service Building	360
3	Building -C	920	**8**	Green areas	1600
4	Building -D	920	**9**	Paved Areas	7350
5	Building -E	720	**-**	------------------	-------
Total site contents and Roof Top area					**6890**
Total site Area					**15840**

Figure 9: The Debbieh Campus (Case A) (numbers refer to the site contents, see Table 6) (Google, 2018) (Source: Author)

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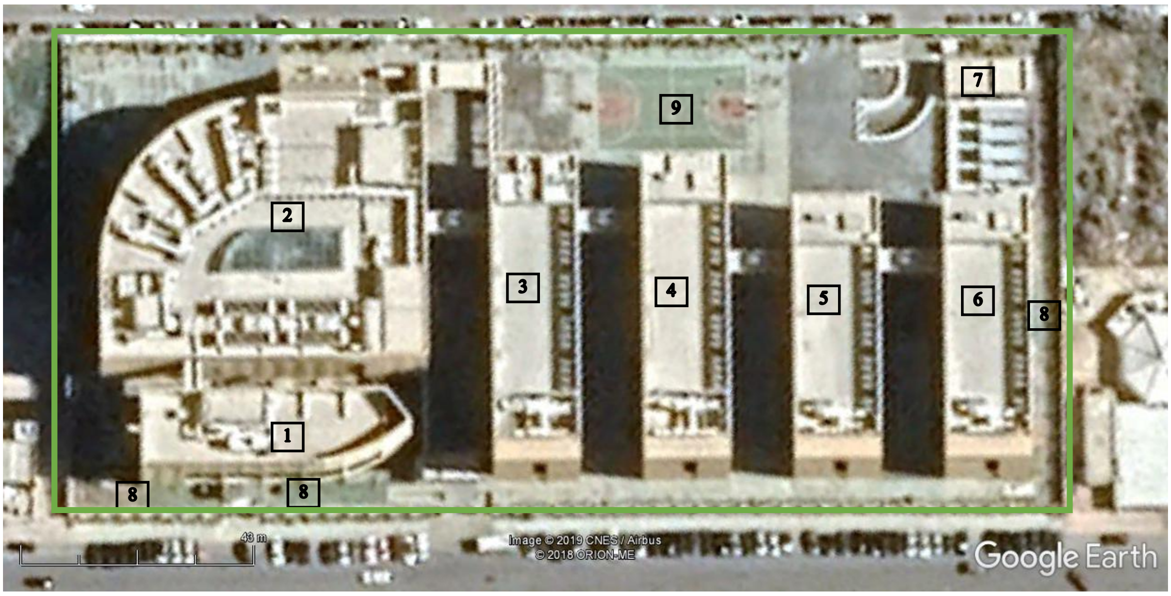

Figure 10: The Tripoli Campus (Case B) (numbers refer to the site contents, see Table 6) (Google, 2018) (Source: Author)

It also calculates in general the estimated cost of the RWH volume per Liter collected from buildings (limited to the tank cost according to the average ratio calculated in the theoretical part) and from site (for the artificial lake cost only). The artificial lake cost was estimated according to a previous project executed by the Chouf municipality (24.3$/m3) (Zeineddine, 2008); this cost was for 2008, so it should be multiplied by the difference between the Consumer Price Index (CPI) from 2008 to 2019 (110%-80%=30%) which is equal to 31.59$/m3 (Trading Economics, 2019).

Then the experimental study calculates the total cost of the overall system components based on the average ratios calculated in the theoretical part. The payback period of the investment is the measurement tool for the economical efficiency of the system, by comparing the result with the water price. The Cost of domestic water from the governmental network in Lebanon is 1000 L.L/m3 for the commercial and touristic facilities (North Lebanon Water Establishment, 2019); While the water price reaches to 10000-20000 L.L/m3 from the private water tanks companies (Yaghi, 2014) (Source: Author).

The study assumes that the rainwater collected from the rooftops will be used in the flushing system for the main buildings, while the rainwater collected from the site will be used for irrigation purposes. Choosing flushing and irrigation purposes (non potable uses) require applying first flush filter only to avoid the insects. This reduces the total cost factors, and the RWHS requirements to reach levels 3 and 4 (see table 3). While choosing potable use (drinking and cooking) requires stainless steel cistern and plumping networks that raises the investment and maintenance costs.

The flush water requirements are calculated according to the following three methods: Unit-Based, User-Based-01, and User-Based-02 methods. The average water volume needed for the flushing operation for each main building is then calculated according to User-Based methods only; except for the A4 Building in (Case-A), where the flush water is calculated according to the Unit-Based method, since it is not operating with full occupancy (see table 8):

Unit-Based: This method calculates the maximum flush water required when the maximum capacity of the building reaches the ratio for which it was designed, based on the following:

The actual number of toilets and urinal units.

The average flush volume per unit, based on the minimum US standards, which is 6 Liters (1.6 Gallons/Flush) for toilets and 3.8 Liters (1.0 Gallons/Flush) for urinals (The North Carolina Department of Environment and Natural Resources, 2009).

The user design aspect ratio for each unit, based on the average ratio 1 Toilet/Urinal for each 50 users in educational buildings, 75 in restaurants, 125 in sport facilities, and 150 in worship facilities (International code councel ICC, 2018).

The standard frequency rate based on the US average standard of 2.11 visit/day/user (except for dorms, which is 6.5 visit/day/user) for toilets and 1.01 visit/day/user for urinals (Celeste Allen Novak, Eddie Van Giesen, 2014).

User-Based-01: This method calculates the most possible accurate flush water requirement for the existing situation based on the following factors:

The actual number of users per building according to the data collected from the BAU administration for the academic year 2018-2019.

The average flush volume per unit, as mentioned in the first method.

The standard frequency rate, as mentioned in the first method.

User-Based-02: This method calculates the most possible accurate flush water requirement for the existing situation based on the following factors:

The actual number of users per building according to the data collected from the BAU administration for the academic year 2018-2019.

The average water volume used in flushing per day for each user which is 30 liters/user/day (20-40 litres/user/day) for dorms, 3.1 liters/User (2.5 hours/day) for worship buildings, and 10 liters/user (8 working hours) for public buildings (European Commission, 2012). The irrigation area that will use the harvested rainwater is calculated according to the average irrigation volume for shrubs and trees using the drip system in Lebanon (1.5 L/shrub/day) (Al-Housseiny, 2016). The estimated irrigation area needed to plant a fruit tree is calculated according to the maximum required area (100m2/Tree) and the minimum required area (50m2/Tree) (see table 10) (Orange Pippin Fruit Trees, 2019). The tank size estimation is based on the purpose of water uses. For flushing use, the tank size is calculated according to the weekly capacity minimum and the monthly capacity maximum; the calculation takes into consideration the daily flushing water required.

6.2 RESULTS:

The figures and tables below present the effect of the simulation applied on the case studies using three types of calculation methods (User-01 and 02, and Unit).

Table 7: The total annual (RWH) volume (m^3) for Debbieh and Tripoli campuses (Case-A and B) according to the annual rainfall of BAU weather station (1131.5mm/year) for Case-A and (821mm/year) for Case-B, the annual average of the district (975mm/year) for Case-A and (745mm/year) for Case-B, and the 5 effective months (Nov.-Mar.) (Source: Author)

#	Contents	Area	mm/year		Effective 5 months	#	Contents	Area	mm/year		Effective 5 months
			1131.5/821	975/745					1131.5/821	975/745	
		m^2	m^3	m^3	m^3			m^2	m^3	m^3	m^3
Debbieh Campus (Case A)											
1	Architecture Bldg.	4365	3457	2979	2505	12	Astronomical Observatory Dome	20	16	14	11
2	Engineering & Science Bldg.	3350	2653	2286	1923	13	Astronomy piazza	60	54	47	39
3	Laboratories Bldg.	1660	1315	1133	953	14	Sport hall	3000	2376	2048	1722
4	A4 Bldg.	5200	4119	3549	2985	15	Main Sports Field -Track	15160	5146	4434	3729
5	4 Dorm Bldgs.	2160	1711	1474	1240	16	Small Sports Fields	2950	1001	862.88	726
6	Mosque	630	499	430	362	17	Main Amphitheater	6800	2308	1989	1673
7	Mosque piazza	750	679	585	492	18	Secondary Amphitheater A4 Bldg.	6630	2251	1939	1631
8	Cafeteria	150	119	102	86	19	Lake (Under construction)	2950	1669	1438	1209
9	Social Bldg.	520	412	355	298	20	Lake`s Pavement (Under construction)	4620	4182	3604	3031
10	Social Bldg. Piazza	525	475	410	344	21	Roads, sidewalks, and Roundabouts	96600	87442	75348	63368
11	Service Bldgs.	530	420	362	304	22	Parking Lots	14200	12854	11076	9315
Total site contents and Roof Top area								**172850**	**135174**	**116478**	**97958**
Total site Area								**1381809**	**781758**	**673632**	**566524**
Tripoli Campus (Case B)											
1	Building -A	650	374	339	285	6	Building -F	720	414	375	316
2	Building -B	2600	1494	1356	1140	7	Service Building	360	207	188	158
3	Building -C	920	529	480	403	8	Green areas	1600	263	238	200
4	Building -D	920	529	480	403	9	Paved Areas	7350	4827	4381	3684
5	Building -E	720	414	375	316	-	-----------------	------	------	------	------
Total site contents and Roof Top area								**6890**	**3960**	**3593**	**3022**
Total site Area								**15840**	**9050**	**8212**	**6906**

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- From Table 7, the total RWH volume, according to the BAU weather station`s annual average rainfall data, is greater than the total according to the district`s annual average by 18696 m3 (16%) in Case-A and by 838 m3 (10%) in Case-B.
- The total RWH for the five effective months (November-March) is around 85% of the total amount.
- The RWH amount for the five effective months in Case-A is the highest for A4 building, then Architecture building then Engineering & Science building.
- The A4 and Architecture buildings have a common linked area as well as the Engineering & Science and Laboratories buildings (see figure 9).

Table 8 The total daily and annual flush water requirement volume (m^3) for the two case studies (A and B) main buildings according to the 5 effective months (Nov.-Mar.) rainfall (Source: Author)

#	Contents	(RWH) Effective 5 months (m^3)	Users	Water Closets	Urinals	Total Flush volume								
						m^3/day								m^3/year
						User-Based-01	User-Based-02	Unit-Based	Average without unit-based	Average	Full capacity work days	Low capacity work days	Low capacity rate %	total flush /work days
						Debbieh Campus (Case A)								
1	Architecture Bldg.	2505	838	30	16	14	8	22	11	15	196	65	20	2315
2	Engineering & Science Bldg.	1923	2327	50	16	38	23	35	31	32	196	65	20	6429
3	Laboratories Bldg.	953	426	52	15	7	4	36	6	16	196	65	20	1177
4	A4 Bldg.	2985	0	40	4	0	0	26	26	26	196	65	20	5440
5	4 Dorm Bldgs.	1240	300	158	0	12	9	12	10	11	196	65	20	2158
6	Mosque	362	600	6	0	4	2	11	3	6	52	313	20	314
8	Cafeteria	86	150	4	2	2	2	4	2	3	196	65	20	414
9	Social Bldg.	298	200	4	2	3	2	3	3	3	196	65	20	553
14	Sport hall	1722	800	28	18	13	8	53	11	25	36	225	20	859
	Total	**12074**	**5641**	**372**	**73**	**94**	**58**	**203**	**102**	**136**	---	---	---	**19659**
						Tripoli Campus (Case B)								
1	Building -A	285	30	8	8	0.5	0.3	7	0.4	2	196	65	20	83
2	Building -B	1140	302	56	20	5	3	39	4	16	196	65	20	835
3	Building -C	403	229	30	15	4	2	22	3	9	196	65	20	633
4	Building -D	403	176	30	15	3	2	22	2	9	196	65	20	486
5	Building -E	316	708	30	15	12	7	22	9	14	196	65	20	1956
6	Building -F	316	255	30	15	4	3	22	3	10	196	65	20	705
	Total	**2864**	**1700**	**184**	**88**	**28**	**17**	**133**	**23**	**59**	---	---	---	**4698**

Table 9: No. of months covered with (RWH) for flush water, tank sizes (m^3), and flush water shortage (m^3/Year) for the two case studies (A and B) main buildings according to the 5 effective months (Nov.-Mar.) rainfall (Source: Author)

Debbieh Campus (Case A)						Tripoli Campus (Case B)					
#	Contents	No. of months covered with (RWH) for flush water	Tank Size Min.	Tank Size Max.	The flush water shortage	#	Contents	No. of months covered with (RWH) for flush water	Tank Size Min.	Tank Size Max.	The flush water shortage
			m^3/Week	m^3/Month	m^3/Year				m^3/Week	m^3/Month	m^3/Year
1	Architecture Bldg.	12.99	44	193	190	1	Building -A	41.27	2	7	202
2	Engineering & Science Bldg.	3.59	123	536	-4506	2	Building -B	16.40	16	70	306
3	Laboratories Bldg.	9.71	23	98	-224	3	Building -C	7.65	12	53	-229
4	A4 Bldg.	6.58	104	453	-2455	4	Building -D	9.96	9	41	-83
5	4 Dorm Bldgs.	6.89	41	180	-919	5	Building -E	1.94	38	163	-1641
6	Mosque	13.83	6	26	48	6	Building -F	5.38	14	59	-389
8	Cafeteria	2.49	8	35	-328	-	-------	-------	-------	-------	-------
9	Social Bldg.	6.48	11	46	-254	-	-------	-------	-------	-------	-------
14	Sport hall	24.07	16	72	863	-	-------	-------	-------	-------	-------
	Total	**7.37**	**377**	**1638**	**-7586**		**Total**	**7.32**	**90**	**391**	**-1834**

- From tables 8 and 9, the RWH can cover around 7.3 months of the total flush water demand in both Cases A and B (around 61 %). This coverage is not the same for all buildings; for example, in the Sport Hall Building in Case-A, it covers 24 months while in the cafeteria it covers only 2.49 months.
- The RWH from the site and buildings` rooftops in cases A and B can cover the whole year's flushing water demand and exceed it by 59 times in case-A and by 17 times in Case-B. To collect all RWH amount from the buildings` rooftops, there is a need to construct several tanks in Case-A and distribute them across the site according to the main buildings location, while in Case-B it can be either one big tank or several connected tanks.
- According to the average cost ratios calculated in the theoretical part (0.46 $/L), The estimated total cost of the RWHS project in Case-A is 462836$ (1006166L/month), and in Case-B is 109786$ (238665L/month). The cost will increase if the tanks are expanded to cover the flushing needs to be 753480$ (1638000L/month) for Case-A, and 179860$ (391000L/month) for Case-B according to the maximum tank size per month.
- The RWHS in Case-A offers 1006166L/month which costs 671$/month from Governmental Network (GNW), and 10062$/month from the Private Water Tanks Companies (PWTC). In case of covering the shortage of flushing from the excess of irrigation it will be 1638000L/month for a cost of 1092$/month from (GNW) and 16380$/month from (PWTC). The same applies for Case-B where the cost ranges from 159$/month (239000L/month) to 261$/month (391000L/month) for the water paid from (GNW), and 2390$/month to 3910$/month from (PWTC).
- Therefor the payback period for Cases A and B will be around 57.5 years for the (GNW) and 3.8 years for the (PWTC). This estimation excludes the maintenance and operation costs that will expand the period to around 85 years for (GNW) and 5.6 for (PWTC).

Table 10 The No. of Shrubs/Trees could be irrigated using the harvested rainwater (1.5L/Shrub-Tree/Day), the area to be irrigated (m^2) for the two case studies (A and B) main buildings according to the effective 5 months (Nov.-Mar.) rainfall (Source: Author)

#	Contents	(RWH) Effective 5 months	No. of Shrubs/Tree (1.5L/Shrub-Tree/Day)	Area to be irrigated m^2		
		m^3	Shrub or Tree/year	Max. 100 m^2/Tree	Semi. 50 m^2/Tree	Average
Debbieh Campus (Case A)						
7	Mosque piazza	492	899	89860	44930	67395
10	Social Bldg. Piazza	344	629	62902	31451	47177
11	Service Bldgs.	304	556	55564	27782	41673
12	Astronomical Observatory Dome	11	21	2097	1048	1573
13	Astronomy piazza	39	72	7189	3594	5392
15	Main Sports Field -Track	3729	6811	681141	340570	510856
16	Small Sports Fields	726	1325	132544	66272	99408
17	Main Amphitheatre	1673	3055	305525	152762	229144
18	Secondary Amphitheatre A4 Bldg.	1631	2979	297887	148943	223415
19	Lake (Under construction)	1209	2209	220907	110453	165680
20	Lake`s Pavement (Under construction)	3031	5535	553539	276770	415154
21	Roads, sidewalks, and Roundabouts	63368	115740	11574003	5787002	8680502
22	Parking Lots	9315	17014	1701355	850677	1276016
Total		**85873**	**156845**	**15684512**	**7842256**	**11763384**
Tripoli Campus (Case B)						
7	Service Building	158	288	28838	14419	21629
8	Green areas	200	366	36620	18310	27465
9	Paved Areas	3684	6729	672892	336446	504669
Total		**4042**	**7384**	**738350**	**369175**	**553763**

- From Table 10, the RWH estimated volume for irrigation purposes covers 156845 Shrubs/Trees in Case-A and 7384 Shrubs/Trees in Case-B; the minimum area required for Case-A is 6 times greater than the site area, and 23 times greater for Case-B.
- From Tables 8-10, the volume of RWH collected for irrigation (from site contents/open spaces) exceeds the actual need in Case-A by 83.3% (14312.17 m3 needed for irrigation out of 85873

m3 collected), and by 95.7% in Case-B (175.74 m3 needed for irrigation out of 4042 m3 collected).

Table 11: Analytical results for the RWH from the case studies` rooftops (Source: Author)

	Case-A	Case-B
Total area of rooftops (m^2)	21035	6530
RWH for the 5 effective months (m^3)	12074	2864
Annual average of the district (mm/year)	975	745
RWH per unit area (m^3/ m^2)	0.57	0.44
RWH per annual average per area (m^3/mm/ m^2)	0.000589	0.000589
Total flush/work days (m^3/year)	19659	4698
Flush demand per area (m^3/ m^2)	0.22	0.18
Flushing demands covered from RWH %	61.42	60.96

Table 12: Analytical results for the RWH from the case studies` site contents/open spaces (Source: Author)

	Case-A	Case-B
Total area of site contents (m^2)	151795	9310
RWH for the 5 effective months (m^3)	85873	4042
Annual average of the district (mm/year)	975	745
RWH per unit area (m^3/ m^2)	0.57	0.43
RWH per annual average per area (m^3/mm/ m^2)	0.000580	0.000583
Unit area to be irrigated from (RWH) (m^2)	11763384	553763
Unit area to be irrigated from (RWH) per annual average (m^2/mm)	12065.01	743.31
Unit area to be irrigated from (RWH) per annual average per collected unit area (m^2/mm/ m^2)	0.079	0.080

- From Table 11, the average of RWH per unit area collected from case studies' rooftops for the five effective months is 0.51 m3/ m2, and 0.51 m3/ m2 for case studies' site contents. The average of the RWH between the two case studies per the annual average per unit area is 0.000585 m3/mm/ m2.
- The average flushing water demand for each unit built up area in the two case studies is 0.20 m3/ m2, and the flushing demand that has been covered from RWH is around 61.19% of the total demand.
- From Table 12, The unit area that could be irrigated from the RWH for each mm of the annual rainfall average per the unit area of the collecting area is 0.795 m2/mm/ m2 as an average between the two case studies.

6.3 DISCUSSION:

- The RWH method applied in the two case studies is classified as Micro Catchment. Rainwater collected from the rooftop catchment area and the external catchment run-off are assumed to be suitable for human contact except for drinking and cooking due to the absence of filtration system in order to reduce the cost.
- From the RWH requirements matrix (Table 3), the Levels 3 and 4 for micro scale projects are fully achieved in Case-A and level 2 is almost achieved. On the other hand, Case-B fully achieved the Levels 2, 3 and 4 which expand the scope of the RWH usage. Level 01 was not achieved in the two case studies due to the high quality requirements including filtration systems which need a higher cost to be established.
- The high value of the RWH volume calculated from the BAU weather station's annual average rainfall data compared to the district's annual average rainfall data cannot provide a base for the RWH project calculations.
- The five effective months (November – March) which produce 85% of the total RWH amount are considered as lying within the peak working months at BAU (September-May). Therefore, this can provide a base for the RWH project Although the average value of RWH on rooftops can cover only around 61% of the flush water demand in the 2 case studies, some buildings exceed the annual flush water demands. The RWH value is directly proportional to the rooftop area, the larger the rooftop area the more RWH covers the flush water demands. Therefore, and in order not to loose the overflow in some rooftops to the sewer network, RWH tanks should be linked together with network pipes for adjacent buildings such as all buildings in Case-B and the Architecture/A4 Buildings and the Engineering & Science/Laboratories Buildings in Case-A (see figures 9 and 10). For non-adjacent buildings overflow can be diverted to the

RWH network of the site for irrigation purposes (if needed for long term storage) or to the sewer network.

- Based on the high excess of RWH amounts collected from site contents for irrigation, this excess can be used to cover the shortage of flush demands resulted from the RWH amounts collected from rooftops. In Case-A, the extra amount of RWH collected from site contents is 74.5% (63975.83 m3) after covering the actual needs for irrigation and the shortage in flushing, while it reaches 50.3% (2032.3 m3) in Case-B.
- The extra RWH amount collected in the two case studies could be used for Hydroponics, Aquaponics, and green walls. It could also be used in the adjacent urban community spaces like streets, or sold to adjacent compounds to cover part of the RWH network's maintenance cost.
- The flushing water in Case-A (19659 m3) can be re-used as grey water after being treated in the sewage treatment stations already established in Debbieh Campus to expand the non edible planted area. The sewage treatment stations produce 110 m3 treated water/day and are actually irrigating the total site planted areas except for the summer months where there is shortage. This method can save the amount of the RWH, cover the current shortage in the treated water during summer months, and decrease the volume of the storage tanks needed for RWH.
- The Artificial Lake in Case-A can store 19175 m3 with an average of 6.5m depth; which means that there is a 66698 m3 extra (RWH) volume that needs around 3.5 lakes to store it. The estimated cost of the lake will be 605738$ when the construction is finished; which means that it is not feasible to construct 2.5 additional lakes, especially since the RWH for irrigation exceeds demand six-fold.

7. CONCLUSION:

As a result, from all of the above, the following can be concluded:

- The levels 3 and 4 of RWH requirements for micro scale projects are the simplest requirements that can be easily implemented in the Coastal Zone and provide a good water quality suitable for human contact except for drinking and cooking. Level 2 can also be implemented but requires more preparation and higher cost. Level 1 is the complete and most expensive level that produces drinking water.
- 85% of the rainfall rate in the Lebanese Coastal zone is located in the five effective months (November-March), so this can provide the base for the RWH project calculations.
- The Unit-Based method shows the overstatement of the fixtures in the existing buildings, such as the Laboratories building that exceeds the actual water demand by 30m3 (about 6 times the actual need). Therefore, this method is not the best to apply in the current situation but it can be used for non-used buildings' estimation.
- The annual RWH average that can be collected from the unit area in the Coastal Zone is 0.505 m3/m2, and 0.000585 m3/m2 for each mm of the annual rainfall average. For instance, these numbers can be used for estimating the volume of the annual RWH collected in an area within the Coastal Zone.
- The RWH volume can cover more than half of the flushing demands in public buildings, and provide twenty times the drip irrigation demand in this climatic zone (according to Case-B), and can exactly irrigate 0.745 m2 for each mm of the annual rainfall average per unit area of the catchment surface. For instance, this number can be used for estimating the irrigation area that can be covered by the RWH.
- The economical factor failed to achieve the efficiency due to the long investment payback period compared to water price offered by the governmental networks in the eligible sites such as Case-B. However, it could be achieved for the sites that depend on the (PWTC) and the sites that are far from the governmental networks such as Case-A which depends on the water coming from 3 wells with high investment, operation and maintenance costs, which is almost the same for the (RWHS) cost.

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