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Estimation of Water and Energy Saving by Rainwater Harvesting: Sulaimani City as a Case Study

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ABSTRACT

Rainwater harvesting could be a possible solution to decrease the consequences of water scarcity and energy deficiency in Iraq and the Kurdistan Region of Iraq (KRI). This study aims to calculate the water and energy (electricity) saved by rainwater harvesting for rooftops and green areas in Sulaimani city, KR, Iraq. Various data were acquired from different formal entities in Sulaimani city. Moreover, Google Earth and ArcMap 10.4 software were used for digitizing and calculating the total rooftop and green areas. The results showed that for the used runoff coefficients (0.8 and 0.95), the harvested rainwater volumes were 2901563 and 12197131 m^3 during the study period (2005 – 2006) and (2019-2020). Moreover, by comparing the study area's rainwater harvesting volume and water production, the water-saving percentage was 8.21 to 22.68%. Furthermore, the energy-saving percentage recorded was from 7.70 to 22.5% by implementing rooftop rainwater harvesting. On the other hand, using average daily rainfall data for the year (2005-2020), the total water-saving percentage and the total energy-saving rate for both runoff coefficients were very close. Water and energy-saving results were calculated using year-by-year rainfall data, taking more time and effort for its computation. Moreover, the water-saving percentage for the selected green area was not encouraging, and the results were between 0.73 and 11.15%. Additionally, the storage size for three typical buildings was calculated, and the results show the average storage size required for rainwater harvesting using daily rainfall data was 11.2 to 14.68 m^3 (house), 291.42 to 422.33 m^3 (school), and 10.5 to 11.41 m^3 (hotel) for runoff coefficients of 0.8 and 0.95, respectively.

Keywords: Rainwater harvesting, Energy saving, Water saving, Kurdistan Region, Iraq.

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تقدير توفير المياه والطاقة عن طريق جمع مياه الأمطار: مدينة السليمانية كدراسة حالة

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الخلاصة

يمكن أن يكون تجميع مياه الأمطار حلاً محتملاً لتقليل عواقب ندرة المياه ونقص الطاقة في العراق وإقليم كردستان العراق. تهدف هذه الدراسة إلى حساب المياه والطاقة (الكهرباء) التي يتم توفيرها من خلال تجميع مياه الأمطار لأسطح المنازل والمناطق الخضراء في مدينة السليمانية ، كردستان العراق. تم الحصول على بيانات مختلفة من جهات رسمية مختلفة في مدينة السليمانية. علاوة على ذلك ، تم استخدام برنامجي Google Earth و ArcMap 10.4 لحساب إجمالي المساحات الخضراء والأسطح. أوضحت نتائج الدراسة أنه بالنسبة لكل من معاملي الجريان السطحي (0.8 و 0.95) اللذان تم استخدامهما في الدراسة ، تتراوح حجم مياه الأمطار التى تم تجميعها من 2901563 م^{3} إلى 12197131 م^{3} خلال فترة الدراسة (2005 – 2006) إلى (2019–2020). علاوة على ذلك ، بمقارنة حجم مياه الأمطار المجمعة والإنتاج المائي لمنطقة الدراسة ، كانت نسبة توفير المياه 8.21٪ إلى 22.68٪. تراوحت نسبة توفير الطاقة المسجلة من 7.7٪ إلى 22.5٪ من خلال تنفيذ جمع مياه الأمطار على الأسطح. من ناحية أخرى ، كانت النسبة المئوية الإجمالية لتوفير المياه ومعدل توفير الطاقة الإجمالي لكلا معاملي الجريان باستخدام بيانات متوسط هطول الأمطار اليومي للسنوات (2020–2005) قريبة جدًا من نتائج توفير المياه والطاقة المحسوبة باستخدام البيانات السنوية لهطول الأمطار ، والتي تستغرق المزيد من الوقت والجهد لحسابها .لم تكن نسبة توفير المياه للمنطقة الخضراء المختارة مشجعة ، وكانت النتائج بين 0.73٪ و 11.15٪. بالإضافة إلى ذلك ، تم حساب حجم التخزين لثلاثة مباني نموذجية وأظهرت النتائج أن متوسط حجم التخزين المطلوب لجمع مياه الأمطار باستخدام بيانات هطول الأمطار اليومية كان 11.2 إلى 14.68 م^{3} (منزل) ، و 291.42 إلى 422.33 م^{3} (مدرسة) ، و 10.5 إلى 11.41 م^{3} (فندق) لمعاملات الجريان السطحي 0.8 و 0.95 على التوالي.

الكلمات الرئيسية: جمع مياه الأمطار، توفير الطاقة، توفير المياه، إقليم كردستان، العراق.

1. INTRODUCTION

Water and energy are considered the two most vital needs for humans to live. Energy demand is anticipated to rise continuously due to population growth, booming economies, alterations in consumption modality, and lifestyle changes **(The United Nations World Water Assessment Programme, 2014)**. On the other hand, uneven distribution of water sources on the earth, unplanned water withdrawal from lakes, rivers, and underground aquifers**(SULTANA, 2007; Mbua, 2013)**, and water consumption increase the lead to water scarcity **(Rahi et al., 2019)**.

Many countries in the Middle East face drought conditions, such as Turkey, Syria, Iran, and Iraq **(Hameed, 2013)**. Iraq's climate is considered arid to semi-arid, and this climate is distinguished by low precipitation and high evaporation rate **(Rahi and Abudi, 2005)**. Lack of water is a real challenge in arid to semi-arid regions, but this problem for Iraq is more challenging **(Rahi et al., 2019)**. Iraq, in 2007, declared a drought situation because, in previous years, it received less rainfall than usual. In addition, there is no treaty between Iraq and neighboring countries on the water share of each country from the shared international rivers, which intensifies the competition to control the shared water resources **(Ali and Saaed, 2016).** And the condition worsened for Iraq conducting several dam projects by neighboring countries on Euphrates and Tigris rivers and their tributaries **(Hameed, 2013)**. Because of these two rivers, Iraq was previously far from water shortage problems, but the new projections refer to dry Euphrates and Tigris rivers by 2040 **(Al-Ansari et al., 2013)**. Consequently, in the next few decades, water scarcity in Iraq was very anticipated **(Talib et al., 2019).** So, the optimal operation of available water resources **(Ali and Abed, 2018)** and adapting new techniques are essential to overcome the water shortage problems **(Al-Ansari et al., 2013)**.

Rainwater harvesting can be a possible technique to solve the water shortage problem in the coming years **(Zakaria et al., 2013)**. Rainwater harvesting is collecting and storing water from rainfall-runoff of different sources such as rocks, rooftops, ground surfaces, and other surfaces, then using it for potable and non-potable purposes **(Mati, 2012; Burgess, 2012).** Historically, the rainwater harvesting system is not new, but it was conducted thousands of years ago in early civilizations in Iraq, Egypt, Yemen, and Libya **(Zakaria et al., 2013; Abdullah et al., 2020)**. Additionally, in southeastern parts of the USA and northern regions of Mexico, several conventional types of rainwater harvesting have been used for agricultural and domestic intents. In recent years, attention to rainwater harvesting has been renewed with a new perspective on rainwater harvesting systems (understanding, implementation, and management**) (Oweis et al., 2012)**.

(Al-Ansari et al., 2013) illustrated that the feasibility of rainwater harvesting depends on; the study area's rainfall intensity and distribution, catchment area runoff specification, soil water holding capacity, the storage capacity of the reservoir, agricultural crop of the area, socio-economic situation of the study area. The main advantages of rainwater harvesting are energy and water saving, preserving groundwater, groundwater recharge, reducing the probability of floods in specific areas, maintaining the ecosystem, and decreasing water bills **(Burgess, 2012; Hari, 2019)**.

Generally, rainwater harvesting can be categorized into rooftop and surface (flood) runoff harvesting **(Hari, 2019)**. Rooftop rainwater harvesting is suitable for urban areas where the water is collected from rooftop catchments **(Farreny et al., 2011)**. Then it is stored in tanks or underground reservoirs by implementing artificial recharge systems. Its components consist of a roof, gutter, downspouts, device for removing debris, filter, equipment for water purification, tank to store water, pump, and other water supply system needs **(Burgess, 2012).** On the other hand, in surface (flood) water harvesting, the runoff is harvested from valleys or watercourses **(Rahi et al., 2019)**. Additionally, there are two other types of rainwater harvesting based on the watershed or catchment: micro catchment and macro catchment **(Hameed, 2013; Zakaria et al., 2013)**.

Globally, research in the rainwater harvesting field focused on water saving rather than calculating energy-saving rates **(Jiang et al., 2013)**. Results of a study conducted by **(Karim et al., 2021)** at five commercial buildings in Dhaka, Bangladesh, illustrated that using rainwater harvesting for a normal year climate scenario, the annual energy saving rate was between 174 kWh to 401 kWh. Regarding water saving by using rainwater harvesting, Sultana indicated that water saved from rainwater harvesting could not meet the domestic demand **(Sultana, 2007)**. But, in the study implemented in the Mvog- Betsi, Yaounde, Cameroon, the rainwater harvesting system served effectively as a supplement or backup to the domestic water supply system for the study area **(Ako et al., 2022)**. Furthermore, research in rooftop rainwater harvesting context for energy and water-saving has been carried out in a single household **(Prayogo, 2019; Stang et al., 2021)** or on a large scale **(Campisano et al., 2017; Kaya, 2020; Al-Houri and Al-Omari, 2021)**. Additionally, regarding the parameters that affect the tank design to collect rainwater in a house, **(Ghisi, 2010)** find that it is essential to consider the particular situation of the study area in the rainwater tank sizing calculation. Since for any roof area, the optimum tank size to collect rainwater depends on the seasonal distribution and quantity of rain for the study area **(Abdulla, 2020)**. In the same context, **(Imteaz et al., 2011)** indicated that rainwater tank construction cost payback depends on tank volume, increasing water price in the future, and climate conditions. Also the effectiveness of reducing runoff and flood occurrence potential is assessed by constructing an industrial park in Changting-China **(Zhang and Hu, 2014)**.

On the other hand, previous studies in Iraq, in general, focused on water saving from valleys and streams, using Remote Sensing (RS), Geographic Information System (GIS) with Multi-Criteria Evaluation method (MCE), and other methods to select the best location for rainwater harvesting **(Buraihi and Mohamed, 2015; Al-Khuzaie et al., 2020; Fakher et al., 2022)**. While Kareem used ground modeling software (GMS) to simulate the rainwater diversion process from the ponds to underground via recharge wells in the Jolak basin, Kirkuk city, Iraq. The study result illustrated the effectiveness of surface water diversion into the ground through recharge wells **(Kareem, 2013)**. Moreover, Gharib et al. used the Stormwater Management Model (SWMM), Soil Conservation Service (SCS), and Runoff Coefficient (RC) to calculate the runoff volume and demand met percentage in the Sulaimani heights compound, Kurdistan Region (KR), Iraq **(Gharib et al., 2021)**. Furthermore, in a study performed by **(Al-Khafaji et al., 2022)** in Al-Muthanna Governorate, Iraq, to determine the most appropriate rainwater harvesting system, the study results showed that ponds, semi-circular bunds, and rooftops are considered the best rainwater harvesting systems in the governorate.

In previous studies in Iraq, rooftop rainwater harvesting hadn’t been used to check its potential for saving water and energy. So, this study primarily aims to estimate water and energy (electricity) savings by conducting the rainwater harvesting system in a part of Sulaimani city, KR, Iraq.

2. STUDY AREA

Sulaimani city is administratively the capital of the Sulaimani governorate, and is located in the northeast part of Iraq **(Zakaria et al., 2013; Ncci, 2015)**. For this study, a part of Sulaimani city has been selected, which is the area inside the Malik Mahmood Ring Road with 63 neighborhoods and an area of approximately 27 Km^2, as shown in **Fig. 1**. Based on the information from the directorate of statistics in Sulaimani city, the city's population growth rate was 3% until 2020. Meanwhile, in 2020, the study area's population is estimated to be 531575, representing 58.86% of the total population of Sulaimani city, which is 903067, that feeds by water from the directorate of water in Sulaimani city. The city's weather is distinguished by a dry and warm summer season and cold and wet winter. Additionally, the city's precipitation (rainfall) season generally extends from October to May **(Zakaria et al., 2013)**.

Sulaimani city primarily depends on public networks; these networks suffer from fundamental problems and need rapid maintenance **(UNHCR Iraq Operation, 2007)**. Moreover, due to population growth, lifestyle alterations, and hygiene attitudes **(Al-Manmi et al., 2019)**, Sulaimani city suffers from insufficient potable water supplies. Consequently, the water from the public networks is available for 2 hours every 72 hours on average. Meanwhile, electricity in Sulaimani city is obtained from the national network, which is not stable and fluctuates according to demand from season to season. In turn, fluctuations in electricity supply affect water treatment plants and pumping stations. As a result, the electric power shortage escalates the city's water shortage problem **(Kaassaamani, 2018)**.

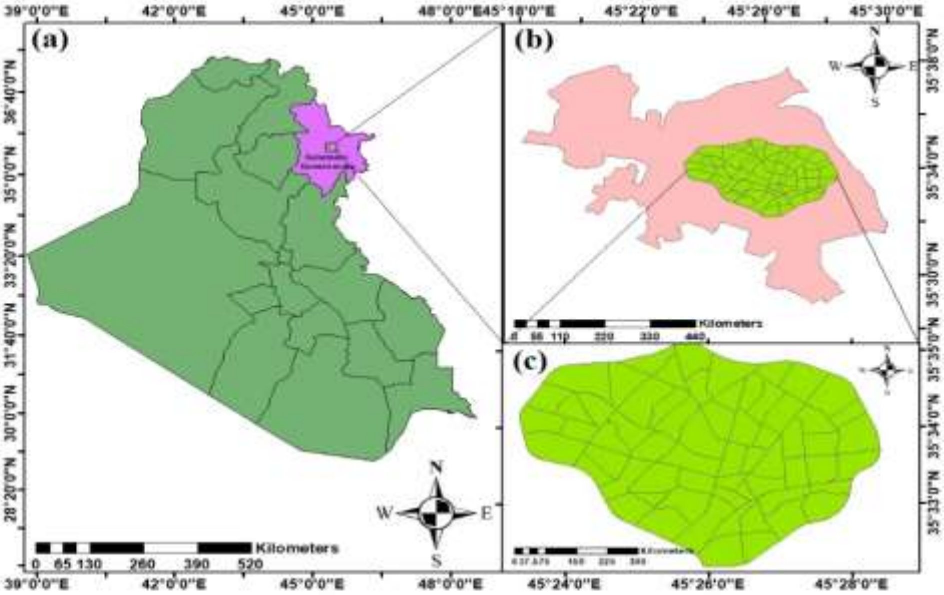

Figure 1. (a) Sulaimani governorate location in Iraq, (b) Sulaimani city, (c) Study area

3. DATA USED

3.1 Rainfall Data

Rainfall data is an essential metrological parameter in roof rainwater harvesting planning. In general, rainwater harvesting is feasible if the rainfall quantity of the study area is at least 300 mm/year, except in the regions where other water sources are minimal. Regarding the period of rainfall data that can be used in the study, at least ten years of rainfall data are required for reliable computation of rainwater harvesting potential in a specified location. In contrast, due to climate change, rainfall data for more than 20 years can create a wrong picture **(Gould, 2015)**. In this work, the available historical daily rainfall data for fifteen rainfall seasons from (2005-2006) to (2019-2020) (October 2005 to September 2020) for Sulaimani city has been used, as shown in **Fig. 2**. The source of the rainfall data was the Directorate of Meteorology and Seismology in Sulaimani.

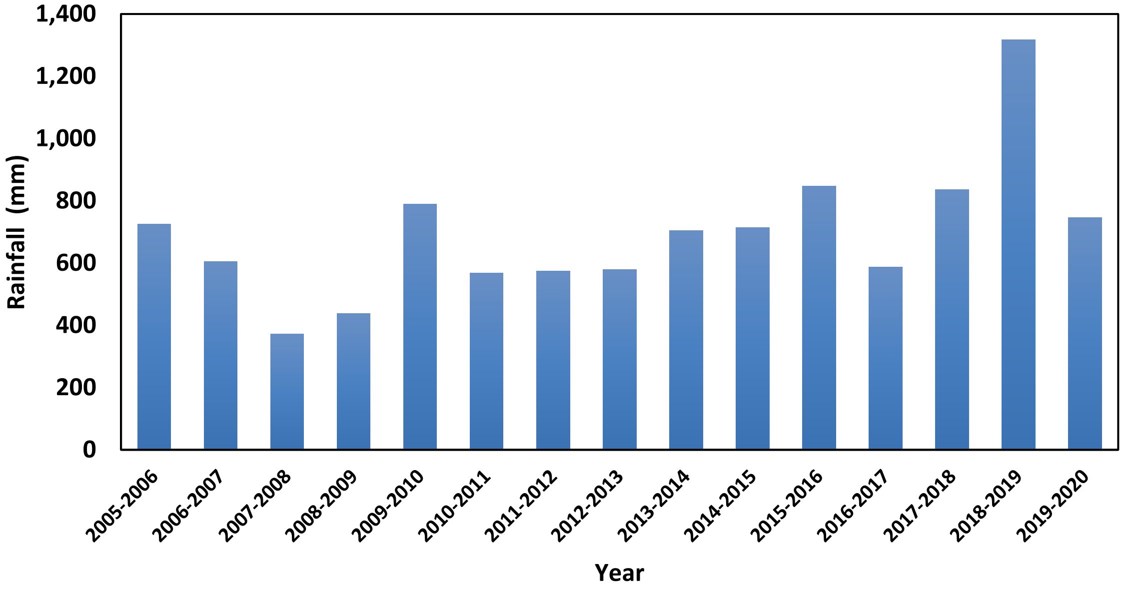

Figure 2. Annual rainfall in Sulaimani city (2005-2020).

3.2 Top Roofs and Public Green Areas

The top roof area can be defined as the size of the horizontal plane of the building roof **(Burgess, 2012).** Regarding the calculation of the total roof area in the present study, an AutoCAD file is used to estimate the roof area of buildings inside Malik Mahmood ring road (study area). The file source was the Presidency of Municipality of Sulaimani-Geographic Information System (GIS) department. Additionally, Google Earth and ArcMap 10.4 software were used for digitizing and calculating the total rooftop areas, as shown in **Fig. 3**.

Figure 3. Building top roofs inside the study area.

Moreover, the total public green areas were delineated and calculated by using the land use AutoCAD file from the same source mentioned previously. By the same procedure, the total public green areas inside the study area have been calculated as shown in **Fig. 4**.

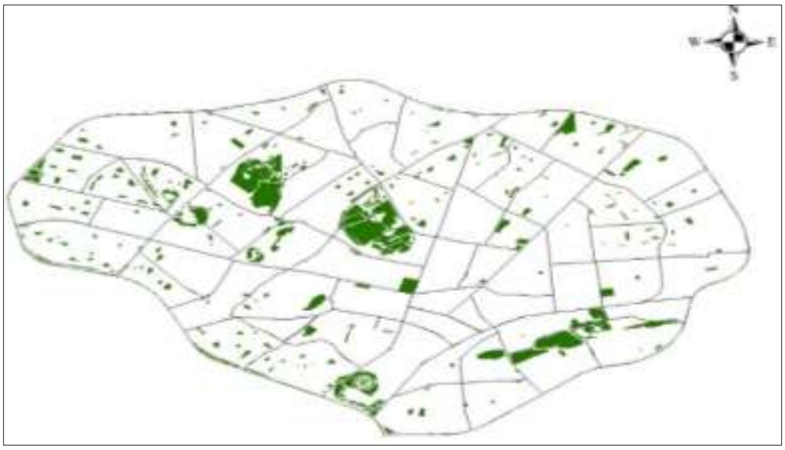

Figure 4. Public green areas inside the study area.

3.3 Runoff Coefficient (Cr)

The runoff coefficient (Cr) can be defined as the volume of water that runs off from a surface or a specific catchment to the volume of the rain that falls on that catchment or surface **(Worm and van Hattum, 2006; Gould, 2015)**. From the definition, it's evident that the runoff coefficient is dimensionless. Moreover, if the runoff coefficient is 0.8, 20% is lost, and the collected rainfall is 80% **(Ghisi, 2010)**. Generally, high rainwater collection is created by an excellent impermeable roof that pollute the rainwater and absorbs the water; for instance, tiles, galvanized corrugated iron sheets, plastic, and concrete are the best choice for roof materials **(Worm and van Hattum, 2006; Hari, 2019)**. Furthermore, the runoff coefficient characterizes the losses due to roof material, evaporation, first flush diversion, and leakage from gutters and downspouts. All the previously mentioned factors contribute to reducing harvested rainfall **(Al-Houri and Al-Omari, 2021)**. On the other hand, no previous studies in Iraq or the study area indicate the runoff coefficient for this location. In the selection process of runoff coefficient, the fact that the majority of the roof of buildings in Sulaimani city is concrete, in addition to the runoff coefficient that is used in neighboring countries, have been taken into account **Kaya, 2020; Maqsoom et al., 2021)**. Thus, the runoff coefficient of (0.8) and (0.95) is used in this work as a lower and upper limit of (Cr), respectively.

3.4 Water Production

Sulaiman city drinking water is obtained from three primary sources, Dukan 1 – Sulaimani, Dukan 2 – Sulaimani, and Sarchnar water projects, and a secondary source, karezs, and wells, which their share of the total water production is a small fraction. Moreover, to achieve the study objective, water production and information about the power consumption of the pumps that feed the study area by water were collected, as described in the following sections.

3.4.1 Dukan 1–Sulaimani water project

This project conveys water from its intake on the Little Zab (Qashqoli), in the Dukan district Sulaimani Governorate, to the Sarchnar water project by three pump stations: Qashqoli, Pirqurban, and Tasluja, as shown in **Fig. 5**. From Tasluja station, water is transported to Shirkozh tank 1 and then by gravity to the Sarchnar water project. Pirqurban station beside it is a pump station, and it also contains a treatment plant. The pipe diameter used for water transportation is 800 mm carbon steel pipe. Moreover, each station has three pumps; one is a standby. Furthermore, the current capacity of the project is 3000 m^3/hr. Finally, information about pumps currently in operation was obtained from the project engineers, as presented in **Table 1.**

Figure 5. Dukan 1-Sulaimani water project scheme.

Table 1. Dukan1-Sualimani project working water pumps.

No.	Pump Station	Discharge (m^3/h)	Head (m)	Volt (V)	Ampere (I)	Power Factor (cosΘ)	Input Power (kW)	Output Power (kW)	Input Power Consumption (kWh/m^3)	Output Power Consumption (kWh/m^3)
1	Qashqoli (Intake)	1800	132	11,000	64	0.85	1,036	960	0.58	0.53
2		1800	132	11,000	64	0.85	1,036	960	0.58	0.53
3	Pirqurban (WTP)	1627	257	11,000	118	0.86	1,933	1850	1.19	1.14
4		1627	257	11,000	118	0.86	1,933	1850	1.19	1.14
5		3000	Clarifiers and treatment facilities				425	425	0.14	0.14
6	Kotal	1627	295	11,000	131	0.86	2,146	2050	1.32	1.26
7		1627	295	11,000	131	0.86	2,146	2050	1.32	1.26
	Total	13108					10657.75	10145.00	6.31	6.00

3.4.2 Dukan 2–Sulaimani water project

The project's intake is also located on the Little Zab (Qashqoli) to transport water to its final destination (Sarchnar water project). It uses four pump stations, Qashqoli, Pirqurban, Kotal, and Tasluja, as shown in **Fig. 6**; about 1500-2000 m^3/hr water is conveyed to some districts and sub-districts from the Tasluja station, and the remaining transported to Shirkozh tank 2, then water is transported to the Sarchnar water project by gravity. While Pirqurban station is a pump station, it also contains a treatment plant to purify the raw water from the Qashqoli station. Moreover, there are 14 pumps, 2 on standby, and now only eight pumps are in operation, and the rest have defects. This project has 1400 mm GRP pipe and 200 mm steel pipe pipelines. Furthermore, the total current capacity of the project is 8000 m^3/hr. Finally, all information collected for Dukan 1–Sulaimani water project about pumps currently in operation is also collected and presented in **Table 2**.

Figure 5. Dukan 2-Sulaimani water project scheme.

3.4.3 Sarchnar water project

Sarchnar water originally is a spring inside Sulaimani city. Sarchnar water project pumps the water to the tanks inside the study area, as shown in **Fig. 7.**

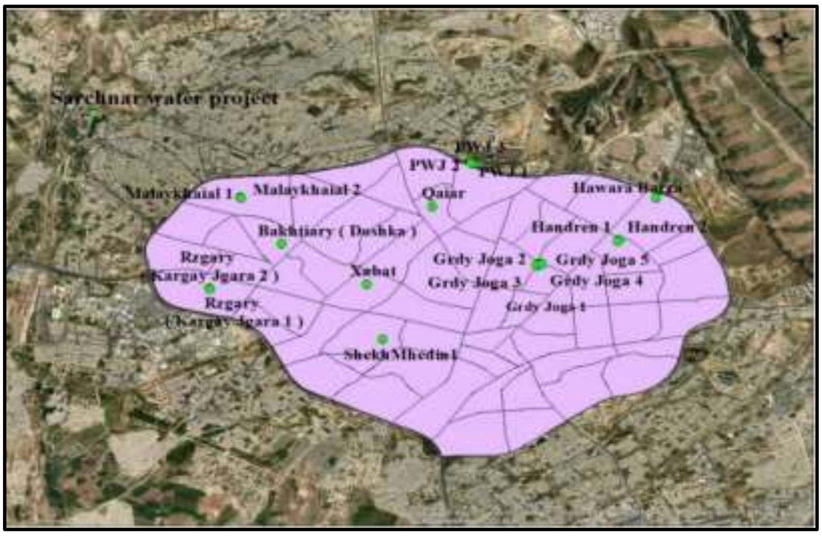

Figure 6. Sarchnar water project and tanks inside the study area

The project contains 39 pumps currently; only 11 of them are working, and the others have defects or do not serve the study area, as presented in **Table 3**. Moreover, based on the variation in its water production from season to season or year to year, it takes water from Dukan 1 and Dukan 2– Sulaimani water projects to fill the drinking water demand of the study area. Meanwhile, the current pumping capacity of the project is approximately 7000 to 8000 m^3/hr.

Table 2. Dukan 2-Sualimani project working water pumps

No.	Pump Station	Discharge (m^3/h)	Head (m)	Volt (V)	Ampere (I)	Power Factor (cosθ)	Input Power (kW)	Output Power (kW)	Input Power Consumption (kWh/m^3)	Output power Consumption (kWh/m^3)
1	Qashqoli (Intake)	1000	154	6,600	65	0.84	624	600	0.62	0.60
2		1000	154	6,600	65	0.84	624	600	0.62	0.60
3		1000	154	6,600	65	0.84	624	600	0.62	0.60
4		1000	154	6,600	65	0.84	624	600	0.62	0.60
5		1000	154	6,600	65	0.84	624	600	0.62	0.60
6		1000	154	6,600	65	0.84	624	600	0.62	0.60
7		1000	154	6,600	65	0.84	624	600	0.62	0.60
8		1000	154	6,600	65	0.84	624	600	0.62	0.60
9	Pirqurban (WTP)	1000	230	6,600	100	0.84	960	925	0.96	0.93
10		1000	230	6,600	100	0.84	960	925	0.96	0.93
11		1000	230	6,600	100	0.84	960	925	0.96	0.93
12		1000	230	6,600	100	0.84	960	925	0.96	0.93
13		1000	230	6,600	100	0.84	960	925	0.96	0.93
14		1000	230	6,600	100	0.84	960	925	0.96	0.93
15		1000	230	6,600	100	0.84	960	925	0.96	0.93
16		1000	230	6,600	100	0.84	960	925	0.96	0.93
17		8000	Clarifiers and treatment facilities				1,250	1250	0.16	0.16
18	Kotal	1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
19		1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
20		1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
21		1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
22		1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
23		1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
24		1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
25		1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
26	Tasluja	1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
27		1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
28		1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
29		1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
30		1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
31		1000	257	6,600	119	0.84	1,143	1020	1.14	1.02
	Total	38000					29923.03	27730.00	28.83	26.64

Table 3. Sarchnar project working water pumps.

No.	Station	Discharge(m^3/h)	Head (m)	Volt (V)	Ampere (I)	Power Factor (cosθ)	Input Power (kW)	Output Power (kW)	Input Power Consumption (kWh/m^3)	Output Power Consumption (kWh/m^3)
1	Hall (1)	700	200	400	1000	0.86	595.83	575	0.85	0.82
2		700	200	400	1000	0.86	595.83	575	0.85	0.82
3		700	200	400	1000	0.86	595.83	575	0.85	0.82
4		700	200	400	1000	0.86	595.83	575	0.85	0.82
5		680	200	400	957	0.89	590.10	575	0.87	0.85
6	Hall (2)	700	200	3300	123	0.86	604.61	575	0.86	0.82
7		700	200	3300	123	0.86	604.61	575	0.86	0.82
8	Hall (3)	700	130	3300	76.6	0.86	376.53	360	0.54	0.51
9		680	200	400	887	0.89	546.93	510	0.80	0.75
10		400	200	400	520	0.91	327.84	315	0.82	0.79
11	Hall (7)	400	250	380	677	0.90	401.03	400	1.00	1.00
	Total	7060					5834.96	5610	9.16	8.83

4. METHODOLOGY

4.1 Rooftop Rainwater Harvesting

In general, the amount of rainfall that can be harvested mainly depends on rainfall data, roof area, and runoff coefficient (Cr) **(Mbua, 2013; Gould, 2015)**. Eq. (1) was used to calculate runoff or volume of rainwater harvested **(Worm and van Hattum, 2006)**:

$$\mathrm{S} = R.A.Cr/1000 \qquad (1)$$

where S is the runoff or harvested rainwater (m^3/time), R is the rainfall (mm/time), A is the roof area (m^2), and Cr is the coefficient of runoff.

4.2 Green Area Rainwater Harvesting

The total public green spaces inside the study area are 1868662 m^2, 6.92% of the entire study area. In this section, inside the study area, a public garden with a total area of (2670 m^2) in the (Bakhtyary Nwe) neighborhood has been chosen to evaluate its potential to harvest rainwater. It's essential in calculating rainwater harvesting (runoff) generally to select a method that is suitable to the data and parameters that are available and also take into account the complexity and the object of the work with a reasonable error level **(Cronshey et al., 1986; Harb, 2015)**. Considering the previous points, the Soil Conservation Service (SCS) method is regarded as the most appropriate method to calculate runoff (rainwater harvesting) in the case of the garden (our case). Moreover, rainfall data was obtained from the Directorate of Meteorology and Seismology in Sulaimani to estimate the rainwater harvesting for the green area for the same duration as discussed in section 3.1.

Additionally, the characteristic soil data of the public garden was obtained from the Harmonized World Soil Database Viewer (HWSD) software v.1.21, in which the Chromic

Vertisols (Vc) was the dominant soil group. In addition, the soil USDA Texture Classification was light clay. So, the hydrologic soil group of the selected public garden is (D), based on the soil type of the selected public garden **(Pilgrim and Cordery, 1993).**
To find the volume of runoff (harvested rainwater) using the Soil Conservation Service (SCS) method, the following steps must be carried out:
1. Knowing the hydrologic soil group and cover type **(Harb, 2015)**. Find the standard value of CN from the table. This CN is CN II (Average CN) for Antecedent Moisture Condition (AMC II) because the curve number depends on the Antecedent Moisture Condition of the basin (watershed) **(Pilgrim and Cordery, 1993)**.
2. If the surface area was different, find the weighted Curve Number (CN) by multiplying the area of the segment by the Average Curve Number (CN II) obtained from the table, then divide them by the total area after that, summing all results **(Harb, 2015)**.

$$\mathrm{CN_n} = \sum_{i=1}^{n} \frac{\mathrm{A_i\ .\ CN_i}}{\mathrm{Total\ Area}} \tag{2}$$

where: $\mathrm{CN_n}$ is the weighted CN of the area, $\mathrm{A_i}$ is the area of each segment ($\mathrm{m^2}$), and $\mathrm{CN_i}$ is the Curve Number of each segment.
3. After finding the weighted CN of the area for each day according to the five-day antecedent rainfall quantity and growing season and by using tables to find the antecedent moisture condition group (AMC I, AMC II, AMC III) **(Silveira et al., 2000)**, then find the equivalent Curve Number (CN I, CN II, CN III) for each antecedent moisture condition, in which CN II is obtained from the table, as follows **(Chow et al., 1988)**:

$$CN\ I = \frac{4.2\ CN\ II}{10 - 0.058\ CN\ II} \tag{3}$$

$$CN\ III = \frac{23\ CN\ II}{10 + 0.13\ CN\ II} \tag{4}$$

4. Find the potential maximum retention (S) in (mm) **(Harb, 2015)**:

$$\mathrm{S} = \frac{25400}{\mathrm{CN}} - 254 \tag{5}$$

where CN is the equivalent curve number.
5. The initial abstraction ($\mathrm{I_a}$) in (mm) is the amount of water that infiltrated the ground, evaporated, retained in the depressions on the surface, or intercepted by vegetation, and can be computed by **(Harb, 2015)**:

$$I_a = 0.2\ S \tag{6}$$

6. Check if the difference between precipitation and initial abstraction (potential runoff) (P-I_a) is positive or negative:

- If (P-I_a) was positive, then proceeded to the next step to find the runoff depth (Q).
- If (P-I_a) was negative, then assume runoff depth (Q) is zero.

Or the same check can be done by using the precipitation (P) and maximum potential retention (S) **(McCuen, 1998)**:

- If $P \geq 0.2S$, then find runoff depth (Q).
- If $P < 0.2S$, assume runoff depth (Q) is zero.

7. The runoff depth (Q) in (mm) can be found by using the following equation **(Chow et al., 1988; McCuen, 1998)**:

$$Q = \frac{(P - I_a)^2}{(P + 0.8S)} \tag{7}$$

Where P is the precipitation (mm).

8. The volume of runoff (V) in (m^3) for the specific area can be found by **(Harb, 2015)**:

$$V = Q.A \tag{8}$$

Q is the runoff depth (m), and A is the area (m^2).

4.3 Study Area Water Share

Monthly water production for Sulaimani city from 2005 to 2020 has been obtained from the statistics department in the water directorate in Sulaimani. The net water delivered to Sulaimani city has been calculated by deducing the water conveyed from Tasluja station in Dukan 2 – Sulaimani water project to some districts and sub-districts. Additionally, to compute the study area water share from the net water production for Sulaimani city, it is multiplied by 58.86%, the percentage of the study area population, to the Sulaimani city population. To compute the average monthly power consumption, it is necessary to divide the study area water share on water projects using the transportation problem, a special case of linear programming **(Reeb and Leavengood, 2002)**. In general, the objective of the transportation problem model is to figure out the optimum route for transporting merchandise from the supply (sources) to destinations (demands) at the lowest cost and time. Transportation problems can be used in different fields, such as business and economics. Moreover, transportation problems can be applied in engineering, for instance (telecommunications, transportation, manufacturing, and energy) **(Muztoba, 2014)**. General formulation of transportation problems can be defined as the following **(Winston, 2003)**:

$$Minimize\ Z = \sum_{i=1}^{m}\sum_{j=1}^{n} X_{ij}C_{ij} \tag{9}$$

$$\sum_{j=1}^{n} X_{ij} \leq S_i\ (i = 1, 2, 3 \dots m)\ (supply\ constraints) \tag{10}$$

$$\sum_{i=1}^{m} X_{ij} \geq d_j\ (j = 1, 2, 3 \dots n)\ (demand\ constraints) \tag{11}$$

$$X_{ij} \geq 0 \; (i = 1, 2, 3 \ldots m), (j = 1, 2, 3 \ldots n) \quad (non - zero\ constraints) \tag{12}$$

where m is the number of supply points, n is the number of demand points, S_i is the capacity of i_{th} supply, d_j is the demand of j_{th} destination, and C_{ij} is the unit transportation cost between i_{th} (supply point) to j_{th} (demand point).

Additionally, the transportation problem is classified into a balanced transportation problem if supply is equal to demand and an unbalanced transportation problem if supply is not equal to demand. The unbalanced transportation problem could be converted into a balanced transportation problem by Introducing a dummy supply or demand, in which the unit transportation cost between each supply point and demand point is zero.

In this study, an unbalanced transportation problem has been used because the supply from water projects is larger than the demand of the study area water share (58.86% supply from water projects). To solve the problem, an Excel sheet (solver) was prepared based on the unbalanced transportation problem to minimize the power consumption of water conveyed from three water projects to the study area, as described in the next section.

4.4 Power Consumption

The information about pumps in the project was obtained from the in-charge engineers of the water projects. On the other hand, for each of the three sources, the input power has been calculated by using the following equation **(U.S. Department of Energy, 1997)**:

$$P = \frac{V * I * \cos\theta * \sqrt{3}}{1000} \tag{13}$$

where P is the input power (kW), V is the voltage (Volt), I is the current (Ampere), and cosθ is the power factor.

Furthermore, power consumption for one meter cubic of water (kWh/m³) is calculated for each project, Dukan 1– Sulaimani, Dukan 2– Sulaimani, and Sarchnar water project by using the following equation **(Vieira et al., 2014)**:

$$Power\ Consumption/m^3 = \frac{P}{Hourly\ pump\ flowrate} \tag{14}$$

After that, the power consumption per one cubic meter of water for Dukan 1 – Sulaimani and Dukan 2 – Sulaimani is summed with the power consumption of the Sarchnar project to obtain the total power consumed to convey water from each project to the study area. According to the information obtained from the water projects, the study area receives water in different percentages from water projects. This results in different power consumption for one meter cubic of water from each source to the study area. To interpret this information and divide the study area water share on each water project to obtain the average monthly power consumption for one meter cubic of water (kWh/m^3) and monthly total power consumption to deliver water from water sources to the study area (kWh), an unbalanced transportation problem has been used, which is a particular case of linear programming optimization **(Reeb and Leavengood, 2002)**. Finally, the problem was modeled using an Excel solver **(Muztoba, 2014)** to compute the average monthly power consumption for one meter cubic of water and the total power consumed to deliver water to the study area.

In this study, an Excel solver is used to represent the unbalanced situation because supply is larger than demand and calculate the average monthly power consumption for one meter cubic of water in (kWh/m^3). The total minimum cost (power) (kWh) represents the average monthly power consumed in (kWh) to transport water to the study area. Moreover, the optimum water shares from each water source (Dukan 1, Dukan 2, Sarchnar) could be known. The step-by-step illustration of the problem solution is given below:

1. Enter the required data into the Excel solver: supply (monthly water production for Sulaimani city in (m^3)), demand (monthly study area water share in (m^3)), and cost parameters (power consumption used to deliver one meter cubic of water from different projects to the study area in (kWh/m^3)).
2. Use the SUM PRODUCT function in the Excel solver to calculate the total minimum cost (power) in (kWh), which is the sum of the product of the study area (demand) water share in (m^3) from each water project (supply) and cost parameter in (kWh/m^3).
3. Select the minimalization objective and Simplex Linear Programming method in the Excel solver to minimize the power consumption of delivering one meter cubic of water to the study area (kWh/m^3).
4. Finally, calculate the minimum average monthly power consumption (kWh/m^3) by dividing the total minimum cost (power) (kWh) by demand (m^3).

4.5 Water and Energy Saving

The water-saving percentage could be calculated by dividing the annual harvested rainwater volume by the annual water production volume for the study area as follow **(Al-Houri & Al-Omari, 2021)**:

$$Water\ saving\ (\%) = \frac{Annual\ harvested\ rainwater\ volume(m^3)}{Annual\ water\ production\ volume\ (m^3)} \times 100 \qquad (15)$$

Moreover, previous studies conducted in the rainwater harvesting context used domestic or irrigation water demand to compare it with the harvested rainwater volume. On the other hand, the energy-saving percentage was calculated by comparing the power that could be saved by rooftop rainwater harvesting with the power consumed to deliver water to the study area as follow:

$$Energy\ saving\ (\%) = \frac{Power\ saved\ (kWh)}{Power\ consumed\ (kWh)} \times 100 \qquad (16)$$

4.6 Storage Tank Sizing

A storage tank is essential to balance the supply of rainwater harvested and household demand. On any given day or month, if the supply of rainwater harvested is more than the demand, a storage tank is required to store water and use it on days or months when demand is more than the supply **(Mati, 2012)**. This study uses a water balance simulation model to find the tank volume. Furthermore, an Excel sheet can be created using rainfall data on a daily scale **(Rahman et al., 2012)**. To calculate the storage by this method, water year is considered from (2005-2006) to (2019-2020), and the following steps are to be followed **(Harb, 2015)**:

1. Find rainwater harvested volume (R_i) (m^3), which is considered as inflow by using Eq. (1).
2. Find the daily demand volume (D_i) (m^3), on day (i) **(Gharib, 2020; Worm and van Hattum, 2006)**:

$$Domestic\ demand = Water\ use\ per\ day \times Household\ members \tag{17}$$

$$Irrigation\ demand = Water\ use\ per\ day \times Area \tag{18}$$

3. Calculate the cumulative surplus (CS_i) (m^3), in case inflow and water stored for the previous day, were less than the consumption (demand), then the volume of zero is assigned to cumulative surplus (CS_i), and the cumulative surplus (CS_i) can be calculated by using the following equation:

$$CS_i = \begin{cases} 0, (\text{ if } CS_{i-1} + R_i - D_i \le 0 \text{ else}) \\ \quad\quad CS_{i-1} + R_i - D_i \end{cases} \tag{19}$$

where CS_i is the cumulative surplus water for the current day, and CS_{i-1} is the cumulative surplus water for the previous day.

4. Find the design storage capacity (m^3), which is equal to the maximum cumulative surplus (CS_{max}).

This study will calculate the storage tank capacity for a typical building (house, hotel, and school).

5. RESULTS AND DISCUSSION

5.1 Rooftop Rainwater Harvesting

Using Eq. (1) and runoff coefficient (Cr) of 0.8 and 0.95, in addition to daily and average daily rainfall data, the total area of building rooftops from ArcMap 10.4 software equals 9747256 m^2 for the study area, the volume of rainwater harvesting has been calculated. The volume of harvested rainwater is calculated daily for each season (water year) from October to September; then, the monthly harvested rainwater volume is represented each year by converting the monthly rainwater volume to the annual harvested rainwater volume. An annual summary of rainwater harvesting potential volume for water years 2005-2006 to 2019-2020 is presented in **Fig. 8**. Furthermore, average daily rainfall data for the years 2005 to 2020 was used to calculate rainwater harvesting volume for the same years, and the results are presented in **Table 4**. From the results, it is apparent by fixing area and runoff coefficient that the volume of rainwater harvested from 2005 to 2020 takes almost the same pattern as rainfall in the same period. For instance, the rain in the water year 2007–2008 was 372.1 mm, which was the least amount in the period of study, so for the same year, for both runoff coefficients 0.8 and 0.95, the volume of rainwater harvested was 2901563 m^3 and 3445606 m^3 respectively; also, this quantity was the smallest volume calculated during the study span 2005 to 2020.

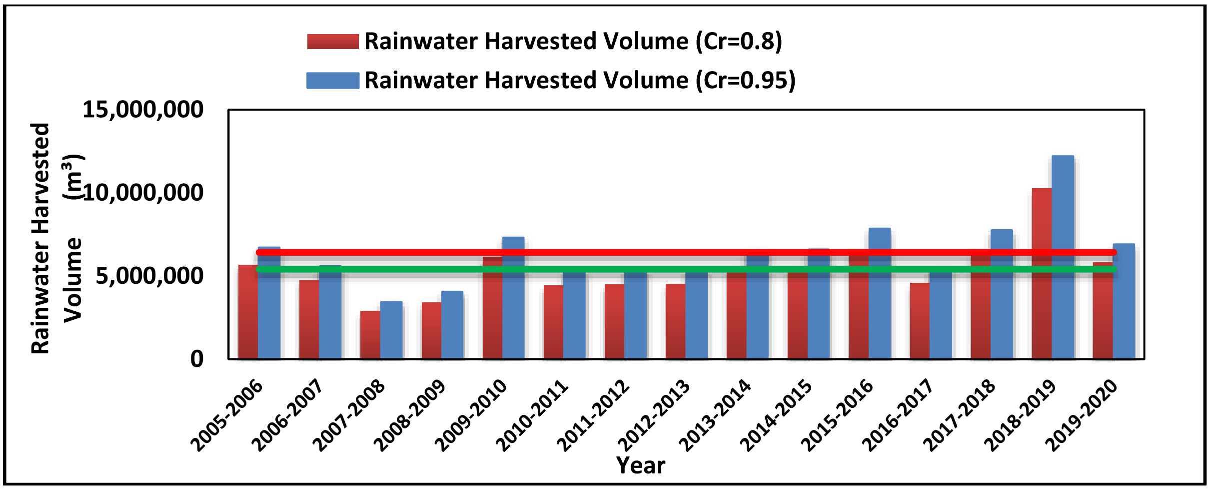

Figure 7. Rainwater harvested for water years 2005-2006 to 2019-2020 for the study area.

On the other hand, in the water year 2018–2019, the rainfall for Cr of 0.8 was 10271268 m^3, and for Cr of 0.95 was calculated to be 12197131 m^3 because the year recorded the highest quantity of precipitation (1317 mm). Eventually, the average rainwater harvested volume was calculated using daily rainfall data for water years 2005-2006 to 2019-2020, and Cr of 0.8 and 0.95 was 5408713.37 m^3 and 6421472.76 m^3, respectively. These values are very close to the total rainwater harvested volume obtained from average daily rainfall data for the study period 2005 to 2020, which were 5408635.39 m^3 to 6422754.52 m^3. Therefore, it is convenient to use the average daily rainfall data for calculating the rainwater harvested volume instead of using daily rainfall data and then calculating the rainwater harvested volume for each year in the study period. As a result, the efforts of calculation will be significantly reduced.

Table 4. Harvested rainwater using average daily rainfall during 2005 to 2020 for the study area.

No.	Year	Month	Rainwater Harvested Volume (Cr=0.8) (m^3)	Rainwater Harvested Volume (Cr=0.95) (m^3)
1	2005-2020	October	348,016.03	413,269.03
2		November	630,608.47	748,847.56
3		December	824,461.90	979,048.51
4		January	787,032.44	934,601.02
5		February	1,003,499.50	1,191,655.66
6		March	853,157.82	1,013,124.92
7		April	691,119.44	820,704.33
8		May	249,763.69	296,594.38
9		June	6,628.13	7,870.91
10		July	0.00	0.00
11		August	77.98	92.60
12		September	14,269.98	16,945.60
Total			5,408,635.39	6,422,754.52

5.1.1 Study Area Water Share

As discussed in section 4.3, the study area water share has been calculated by multiplying the net water production for Sulaimani city by 58.86%, and the results are shown in **Fig. 9.** The water production for Sulaimani city shows an upward trend after the year 2008-2009 due to Dukan 2–Sulaimani water project operation. Moreover, the average study area share of water was 47189820 m^3 for the study span from 2005 to 2020. Additionally, by using the unbalanced transportation problem, as discussed in detail in section 5.1.3, for October 2019, the study area water share was 5034886 m^3; the optimization model divided this volume as follows: 3170972 m^3 for the Sarchnar water project, 1860000 m^3 for Dukan-1, and 3915 m^3 for Dukan-2.

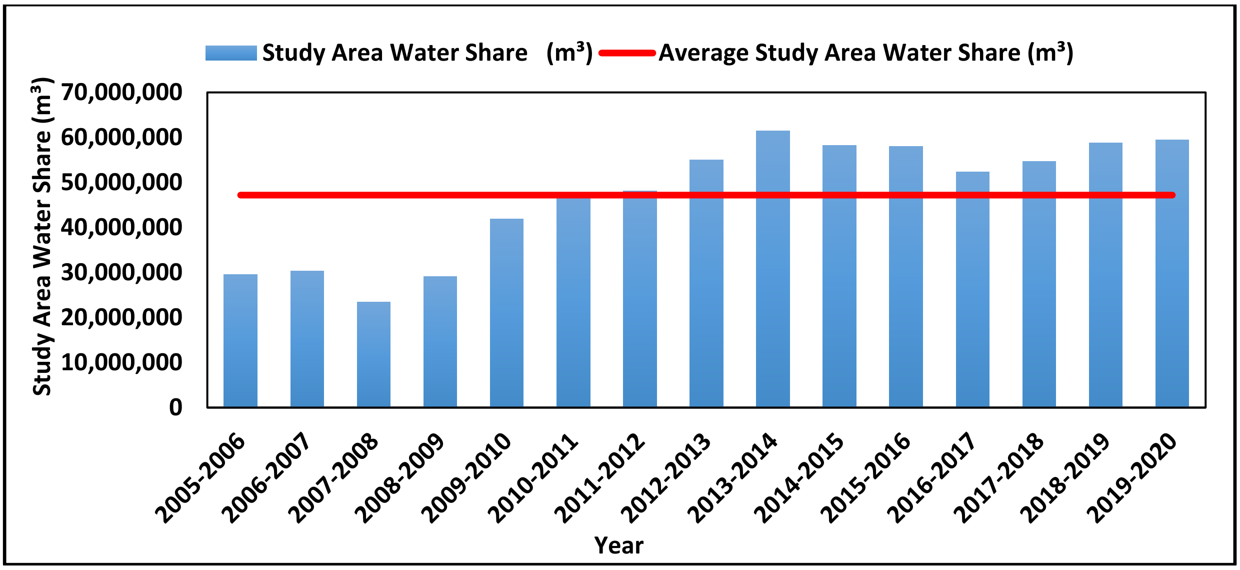

Figure 8. Study area water share for years 2005-2006 to 2019-2020.

5.1.2 Water Saving

The water-saving results are computed by dividing the harvested rainwater volume by water production. Moreover, previous studies conducted in the rainwater harvesting context used water demand to compare it with rainwater harvesting. In this study, the actual water production for the area has been used to calculate the water-saving percentage. **Fig. 10** shows the annual water-saving rate for runoff coefficients (Cr) 0.8 and 0.95. **Table 5.** Shows the water-saving percentage using average daily rainfall data from 2005 to 2020 to calculate harvested rainwater volume for the same period.

The water-saving percentage in the water year (2005–2006) for both runoff coefficients 0.8 and 0.95 was the highest at 19.1 and 22.68 %, respectively. The lowest percentage calculated in the water year (2012–2013) was 8.21 and 9.74%. Finally, the average water-saving percentage, that its harvested rainwater was calculated by daily rainfall data year by year was 11.88 to 14.1%, was very close to the total water-saving percentage of its rainwater harvested volume obtained from average daily rainfall data 11.46 to 13.61% from 2005 to 2020, respectively. As a result, to reduce the calculation effort, average daily rainfall data can be used to calculate rainwater harvesting volume and water-saving percentage. Additionally,

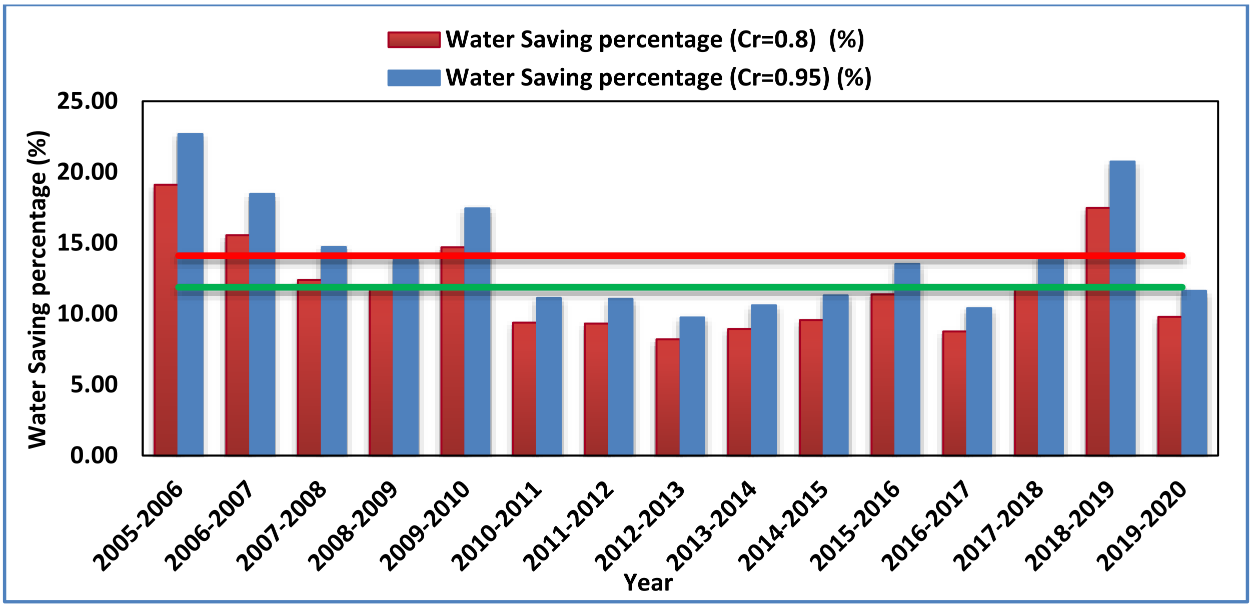

Figure 9. Percentage of water saving for the study area from 2005-2006 to 2019-2020.

Table 5. Percentage of water saving for the study area using average daily rainfall for 2005 to 2020.

No.	Year	Month	Water Saving (%) (Cr=0.8)	Water Saving (%) (Cr=0.95)
1	2005-2020	October	0.74	0.88
2		November	1.34	1.59
3		December	1.75	2.07
4		January	1.67	1.98
5		February	2.13	2.53
6		March	1.81	2.15
7		April	1.46	1.74
8		May	0.53	0.63
9		June	0.01	0.02
10		July	0.00	0.00
11		August	0.00	0.00
12		September	0.03	0.04
Total			11.46	13.61

the water-saving percentages are promising, especially for the coming years, when it's anticipated that the study area will face water shortage due to global warming consequences.

5.1.3 Energy Saving

The power consumption for one cubic meter of water has been calculated for each water project, Dukan 1–Sulaimani, Dukan 2–Sulaimani, and Sarchnar using Eq. (14). After that, the power consumption per one cubic meter of water for Dukan 1–Sulaimani and Dukan 2–

Sulaimani, summed with the power consumption of the Sarchnar project to obtain the total power consumed to convey water from each project to the study area and presented in **Table 6**.

Table 6. Water conveys power consumption from each water project to the study area.

No.	Water Project	Power Consumption (kWh/m^3)
1	Dukan-1 to study area	15.47
2	Dukan-2 to study area	37.99
3	Sarchnar to study the area	9.16

Additionally, the problem is modeled using an Excel solver (unbalanced transportation optimization) to distribute the study water share on each water source, Dukan 1, Dukan 2, and Sarchnar, to compute the average power consumption (minimum) for delivering one meter cubic of water from each water project to the study area (kWh/m^3), and calculating the total minimum power consumption to convey water from water projects to the study area (kWh), for each month, as shown in **Table 7**. Then, this quantity in (kWh/m^3) is multiplied by the volume of harvested rainwater for each runoff coefficient (0.8 and 0.95) to obtain the power that can be saved in (kWh) for each month of the study period 2005-2006 to 2019-2020. The annual summary of results is shown in **Fig. 11**. In addition, an annual summary of the energy-saving percentage for the water years 2005-2006 to 2019-2020 for both runoff coefficients are presented in **Fig. 12**.

Table 7. Study area water share from each water project and average power consumption per cubic meter (October 2019).

Year	Month		Water Projects (Supply)	To Study Area Power Consumption (kWh/m^3)	Water Supply (m^3)		
2019	October	From	Sarchnar	9.16	3,170,972		
			Dukan-1	15.47	1,860,000		
			Dukan-2	37.99	3,522,557		
			Demand (m^3)	5,034,886			
			Total Supply (m^3)	8,553,529			
			Total Demand (m^3)	5,034,886			
			Water Projects (Supply)	To Study Area Water Share (m^3)	LHS	Relation	Water Supply (m^3)
		From	Sarchnar	3,170,972	3,170,972	<=	3,170,972
			Dukan-1	1,860,000	1,860,000	<=	1,860,000
			Dukan-2	3,915	3,915	<=	3,522,557
			LHS	5,034,886			
			Relation	=			
		Demand (m^3)			5,034,886		
		Total Minimum Power (kWh)			57,969,014		
		Average Power Consumption (kWh/m^3)			11.51		

It's evident from the results year (2007-2008) recorded the smallest power-saving quantity, 28621429.07 kWh to 33987947.11 kWh. On the contrary, the year (2018-2019) recorded the highest power-saving quantity with 109356983 kWh to 129861418 kWh. On the other hand, the energy-saving percentage in 2012-2013 of 7.7 to 9.14% is recorded as the lowest saving percentage. While in the season (2005-2006), the energy-saving percentage was the highest, 18.99 to 22.55%.

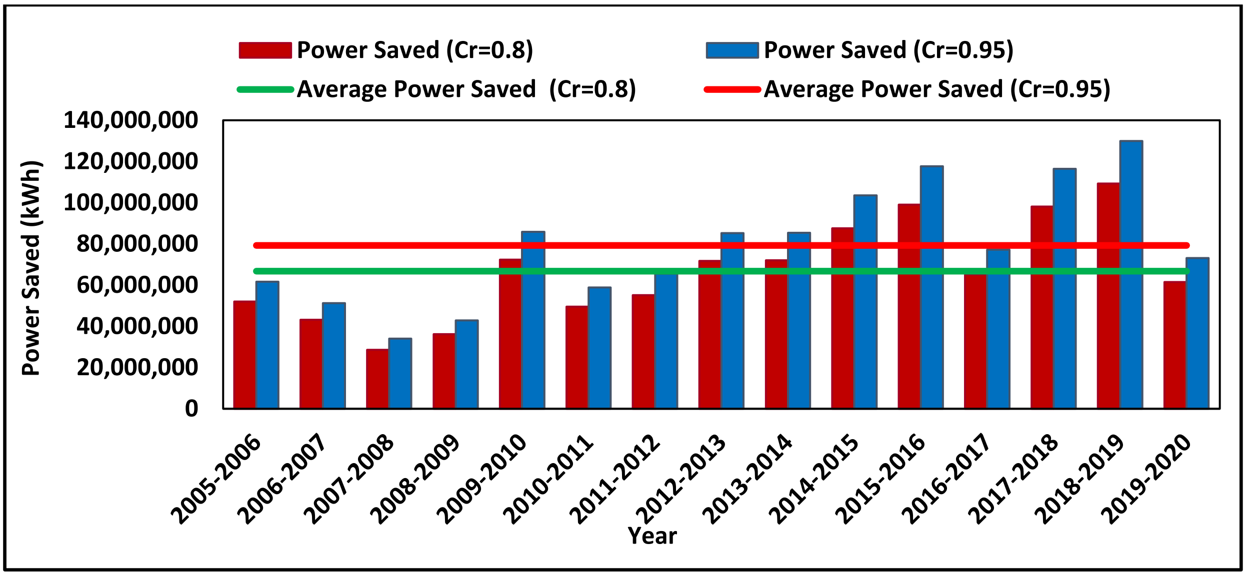

Figure 10. Power saving using rainwater harvesting for the study area for water years 2005-2006 to 2019-2020.

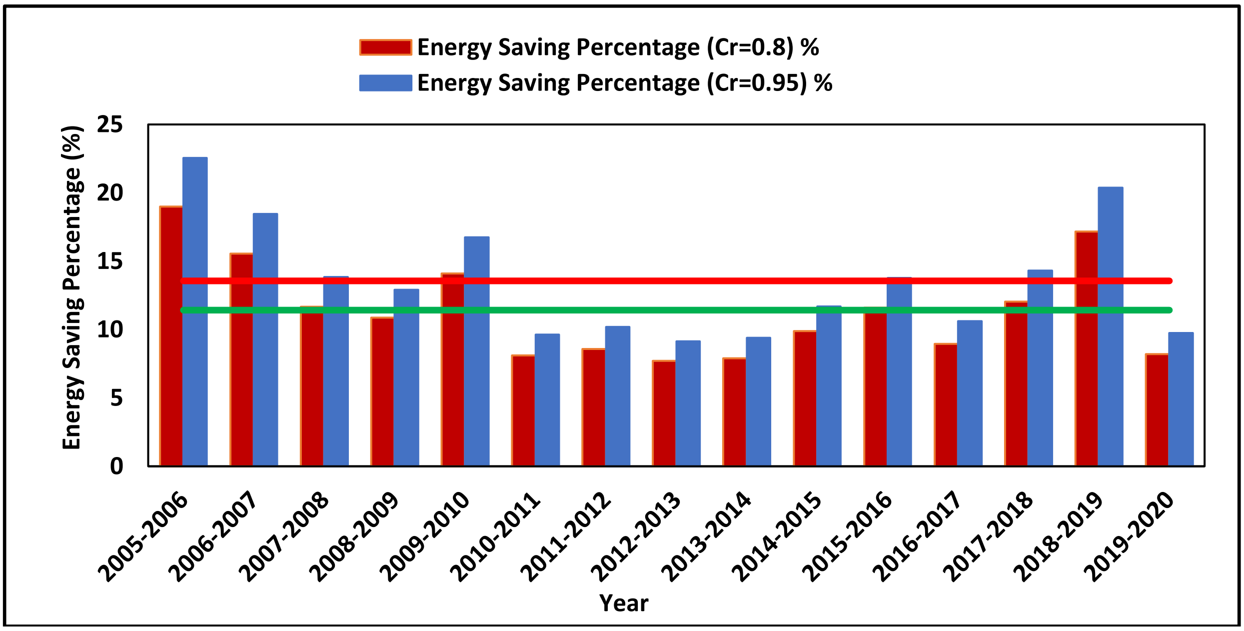

Figure11 . Percentage of energy saving for the study area for water years 2005-2006 to 2019-2020.

Furthermore, the power consumption in (kWh/m^3) is multiplied by the volume of harvested rainwater calculated by average daily rainfall to find the saved power and its percentage for both runoff coefficients for 2005 to 2020, as shown in **Table 8**. From **Fig. 11,** the average power saved quantity (kWh) calculated by daily rainfall data was 66754548.45 kWh to 79246287.82 kWh. While from **Table 8,** the total power saved (kWh) was obtained using rainwater harvested volume from average daily rainfall data recorded to be 65861492.08 kWh to 78210521.93 kWh for the study period 2005 to 2020. Even using the average daily rainfall data to calculate the rainwater harvesting volume to compute the total saved power quantity (kWh) can save calculation time. However, calculating power-saving year by year can provide a clear vision of the effect of water production and rainwater harvesting volume on the power-saving quantity.

On the other hand, from **Fig. 12**, the average energy-saving percentage that harvested rainwater was calculated by daily rainfall data was 11.42 to 13.56%. Meanwhile, the total energy-saving percentage that average daily rainfall data were used to calculate the rainwater harvesting volume ranged from 10.5 to 12.47% from 2005 to 2020, as presented in **Table 8**. As discussed previously, using average daily rainfall data to calculate rainwater harvesting to compute the energy-saving rate can save computation time and effort.

Table 8. Power saving quantity and energy saving percentage using average daily rainfall to calculate harvested rainwater for the study area for 2005-2020.

No.	Year	Month	Total Monthly Power Saved (kWh) (Cr=0.8)	Energy Saving (%) (Cr=0.8)	Total Monthly Power Saved (kWh) (Cr=0.95)	Energy Saving (%) (Cr=0.95)
1	2005-2020	October	4,144,870.92	0.66	4,922,034.15	0.78
2		November	7,321,364.34	1.17	8,694,120.17	1.39
3		December	9,893,542.80	1.58	11,748,582.12	1.87
4		January	9,200,409.22	1.47	10,925,485.92	1.74
5		February	12,292,868.88	1.96	14,597,781.84	2.33
6		March	10,323,209.62	1.65	12,258,811.53	1.95
7		April	8,894,707.19	1.42	10,562,464.73	1.68
8		May	3,514,175.12	0.56	4,173,082.93	0.67
9		June	98,162.61	0.02	116,568.18	0.02
10		July	0.00	0.00	0.00	0.00
11		August	1,090.94	0.00	1,295.47	0.00
12		September	177,090.45	0.03	210,294.90	0.03
Total			65,861,492.08	10.50	78,210,521.93	12.47

5.2 Green Area Rainwater Harvesting

Soil conservation service (SCS) method used with the information presented in **Table 9**, an Excel sheet has been created to calculate the volume of rainwater harvested for a public green area (typical green area) in (Bakhtyary Nwe) neighborhood for water years 2005-

2006 to 2019-2020 by using the daily rainfall data, **Fig. 13** shows rainwater harvested volume from the selected public green area.

In general, the volume of harvested rainwater quantity from the green area is small due to a large amount of initial abstraction (I_a). Moreover, the daily rainfall quantity significantly influences the volume of harvested rainwater because the runoff depth can be calculated only in the case of daily rainfall being higher than the initial abstraction. If not, the runoff depth will equal zero; eventually, rainwater cannot be harvested. From **Fig. 13**, it's clear that the average water that could be harvested from that public green area is 288.61 m^3. If this volume is divided by the park's area, the result is 0.108 m^3/m^2. Then approximately the volume of harvested rainwater for the total green area inside the study area could be computed by multiplying the total green space inside the study area, which is 1868662 m^2 by 0.108 m^3/m^2; the result is 2018155.6 m^3.

Table 9. General characteristics of public green area in the study area.

Total area Park(m^2)	2670
Grass area(m^2)	2415
Grass cover Percentage %	90
Garden soil type	Chromic Vertisols
Hydrologic Soil Group	D
Curve Number II (average from a table)	80
Curve Number I (dry)	63
Curve Number III (wet)	90

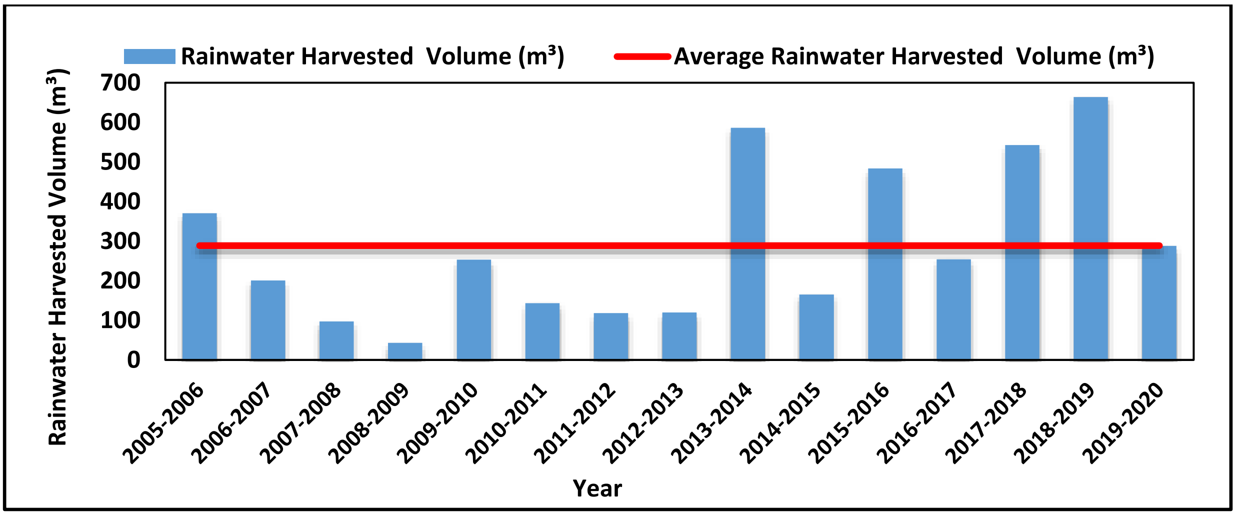

Figure 12. Rainwater harvested for the selected public green area from 2005- 2006 to 2019-2020.

By knowing the daily water requirement for each crop type and its area **(Gharib, 2020)** and using Eq. (18) from the middle of May to the middle of October(Irrigation time in the study area), the irrigation demand for the public garden has been calculated and presented in **Table 10**. After that, for each month, the lawn, trees, and shrub's irrigation water demand was summed. Then the annual irrigation demand was calculated to be 5951.544 m^3. Finally, the water-saving percentage has been calculated using Eq. (15) by dividing the annual harvested rainwater volume for the selected public green area that is presented in **Figure 12** by the total annual irrigation demand for the selected public green area (5951.544 m^3) from **Table 10**, and the results are shown in **Fig. 14**.

The results show the insufficiency of rainwater harvesting from the green area because, for example, in the water year 2008-2009, the rainwater that could be harvested could meet only 0.73% of the selected green area's irrigation water demand, and in the best case as in the water year 2018-2019 it can meet only 11.15 % of irrigation water demand. In addition to its inability to harvest significant water, rainwater harvesting from green areas can face practical challenges. Moreover, the public green spaces in Sulaimani city constructed by the municipality of Suliamani use groundwater from wells and tankers for irrigation. So they put a load on the water treatment plants, requiring less electricity to operate the wells' pumps. Therefore, it is impractical and infeasible economically to implement rainwater harvesting for green areas.

Table 10. Monthly water demand for the selected public green area within the study area.

Crop Type	Month	Irrigation Period (day/month)	Crop Water Requirement (l /day/m^2)	Area (m^2)	Irrigation Water Demand (m^3)
Lawn	May	15	12	2415	434.7
	June	30	16	2415	1159.2
	July	31	16	2415	1197.84
	August	31	16	2415	1197.84
	September	30	16	2415	1159.2
	October	15	12	2415	434.7
Trees and shrubs	May	15	8	216	25.92
	June	30	12	216	77.76
	July	31	12	216	80.352
	August	31	12	216	80.352
	September	30	12	216	77.76
	October	15	8	216	25.92
	Total				5951.544

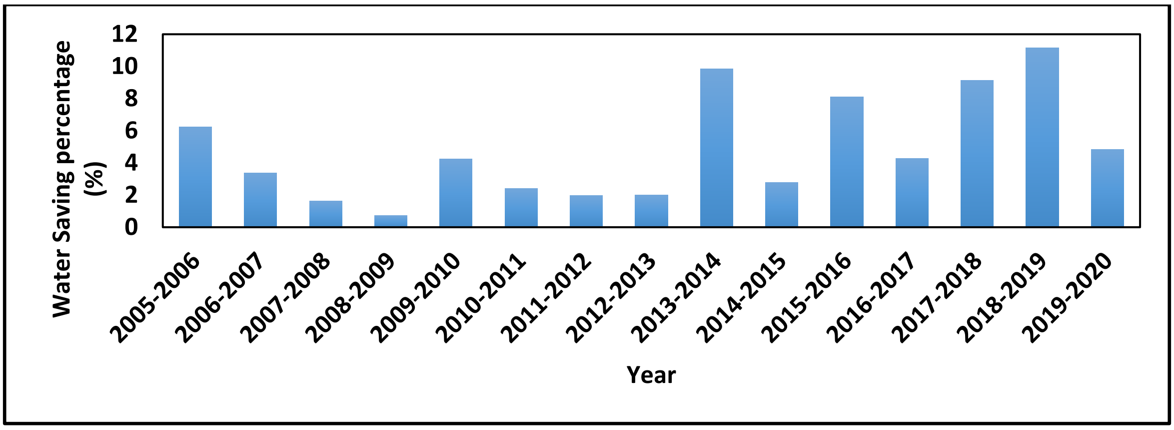

Figure 13. Percentage of water saving for the green areas for water years 2005-2006 to 2019-2020.

5.3 Storage Tank Sizing

In this study, as previously discussed, three buildings (house, school, and hotel) have been selected in the study area to calculate the storage tank required to collect the rainwater that could be harvested. For the house, the selected building has a typical characteristic of the majority of houses in the study area, with a total roof area of 160 m^2 on average. Moreover, the average number of inhabitants in each house has been acquired from the directorate of statistics in Sulaimani city (5 % on average). In addition, the daily demand for water per capita has been obtained from the directorate of water in Sulaimani city (250 liter/capita/day).

Moreover, Ahmady Khani high school for boys inside the study area was selected for calculating the required rainwater harvested tank size for the school building. The school has a roof area of 1760 m^2, 43 teachers, 410 students, and 10 staff. The water demand was assumed to be 10 liters per person per day **(UNICEF, 2012),** and the daily water requirement for each crop type was obtained **(Gharib, 2020).** In July, June, and August (summer holidays), only four people of the staff are there. The total water demand (domestic and irrigation) for the months of the year is presented in **Table 11**.

Additionally, for calculating hotel storage tank size for harvested rainwater, Shahram three stars hotel on Salim Street inside the study area was selected with a roof area of 345 m^2, 105 beds, and 200 liters per bed per day as water demand.

An Excel sheet has been created, the information mentioned above, with the daily and average daily rainfall data and steps illustrated in section 4.6 combined to calculate the storage capacity volume for the typical buildings for the years 2005 to 2020 for runoff coefficients 0.80 and 0.95, and the results have been shown in **Table 12**. The results show that the minimum storage computed for a house in the 2008-2009 ranges from 4.18 to 5.35 m^3 for both runoff coefficients 0.80 and 0.95, respectively, while the maximum storage ranged from 32.04 to 40.62 m^3 in the water year 2017-2018. Meanwhile, the average storage was 11.2 to 14.68 m^3 using the daily rainfall data for water years 2005-2006 to 2019-2020. On the other hand, by using the average daily rainfall data from (2005 to 2020), the storage decreased from 0.41 to 0.73 m^3 because, in this case, the daily rainfall was divided into 15 years, and the average daily rainfall data give the wrong result for storage.

Table 11. Domestic and irrigation water demand for a typical school building.

Month	Irrigation Water Demand (m^3/day)	Domestic Water Demand (m^3/day)	Total Water Demand (m^3/day)
October	6.316	4.63	10.95
November	0	4.63	4.63
December	0	4.63	4.63
January	0	4.63	4.63
February	0	4.63	4.63
March	0	4.63	4.63
April	0	4.63	4.63
May	6.316	4.63	10.95
June	8.484	0.04	8.52
July	8.484	0.04	8.52
August	8.484	0.04	8.52
September	8.484	4.63	13.11

Table 12. Annual storage size for rainwater harvesting for typical buildings in the study area for water years 2005-2006 to 2019-2020.

No	Year	Storage (m^3) - (Cr=0.80)			Storage (m^3) - (Cr=0.95)		
		House	School	Hotel	House	School	Hotel
1	2005-2006	19.48	395.05	14.99	23.60	508.46	21.74
2	2006-2007	6.83	190.84	0.00	9.16	289.13	0.00
3	2007-2008	5.78	127.40	0.00	8.50	157.36	0.00
4	2008-2009	4.18	93.18	0.00	5.35	116.73	0.00
5	2009-2010	12.18	228.93	0.00	15.40	435.06	2.76
6	2010-2011	10.09	217.47	0.00	14.12	272.86	0.00
7	2011-2012	5.44	186.31	0.00	7.08	290.89	0.00
8	2012-2013	6.96	247.34	0.00	8.73	365.77	0.00
9	2013-2014	12.72	296.99	3.32	16.04	423.09	7.87
10	2014-2015	5.68	170.41	0.00	7.45	312.54	0.00
11	2015-2016	11.03	368.09	0.00	18.59	588.16	0.11
12	2016-2017	15.09	185.62	8.31	18.38	291.42	13.81
13	2017-2018	32.04	486.30	15.38	40.62	618.89	22.20
14	2018-2019	14.04	927.87	0.00	19.25	1258.10	0.00
15	2019-2020	6.47	249.47	0.00	7.92	406.50	0.00
Average		11.20	291.42	10.50	14.68	422.33	11.41

For school buildings, the results in **Table 12.** shows that the larger roof area and smaller demand create a larger storage tank volume for all years in the study period for both runoff coefficients. The minimum storage required was in the water year 2008-2009, with 93.18 m^3 to 116.73 m^3. In contrast, the largest storage volume was in the water year 2018-2019, with 927.87 m^3 to 1258.1 m^3, while the average storage required for the study duration was between 291.42 to 422.33 m^3. But if the average daily rainfall data were used for storage calculation, the average storage capacity would drop to 90.38 to 222.02 m^3 for both runoff coefficients used in the study. Comparing these two results shows that average rainfall daily data cannot be used for calculating storage tank volume.

For the hotel, in the majority of years in the study period, for both runoff coefficients used in this study, the computed storage tank volume was zero because the roof area was small and the daily demand of the hotel was large. But in 2017-2018, the computed storage was maximum by 15.38 m^3 to 22.2 m^3. The average storage required for the study duration was 10.5 to 11.41 m^3 using daily rainfall data. To calculate the average storage, only those years accounted for that year's storage volume **(Harb, 2015)**. While, by using the average daily data due to detaching the rainfall during the study time (15 years), in addition to the roof area and demand effect, the computed storage tank volume was zero. As discussed, storage volume calculation for typical buildings (houses, schools, and hotels) using average daily rainfall data gives unreal results for storage tank sizing.

6. CONCLUSIONS

The objective of this study was to estimate the water and energy (electricity) saved by rainwater harvesting for rooftops and green areas in Sulaimani city, KR, Iraq. The study results encouraged water saving using rooftop rainwater harvesting by meeting 8.21% to 19.1% and 9.74% to 22.68% of the study area's water production for runoff coefficients of 0.8 and 0.95, respectively. While the energy saving percentage was between 7.7% to 18.99% for Cr=0.8, and for Cr=0.95 energy saving percentage was from 9.14% to 22.55%. Moreover, from the study results, it's apparent that the water-saving and energy-saving results were close using the average daily rainfall data for the study period or year-by-year daily rainfall data. So, average daily rainfall data can be used to reduce calculation efforts. On the other hand, rainwater harvesting for the selected green area did not encourage saving water, but it can be used to decrease flood occurrence.

Moreover, the study outcome illustrates that daily rainfall, roof area, and demand significantly influence the storage tank's volume. Also, average daily rainfall data could not be used to calculate storage tank size because it gives a wrong result due to dividing daily rainfall over the study period.

Finally, people's perceptions may make implementing rainwater harvesting in the study area difficult. In this case, the government's role is vital to overcoming the obstacles hindering rainwater harvesting.

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