Estimated Quantities of Greywater Resulting from the Ablution Process (Wudu) in Mukalla City's Mosquesas a Strategic Solution to Preserve the Governorate's Water Reserves

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ABSTRACT:

The main objective of the study was to estimate quantities of greywater resulting from the ablution process in the mosques under study (18) and in all mosques in Mukalla city. As well as knowing the percentage of people who use mosque water for the ablution process, and also knowing the quantity of water used by each worshiper. The study was carried out in separate periods of time, from 2008 until 2022. The field survey and the necessary measurements were used to carry out this study. The study showed that 32% of those entering to perform prayer in the mosques under study performed ablution. The average rate of water used by an individual performing ablution is about 4 liters at a time, meaning an average of 20 liters per day. The study also showed that the estimated quantities of greywater resulting from the ablution process in the mosques under study amounted to by 7924.8 m^3/month or 95097.6 m^3/year. Estimates and calculations showed that the estimated quantities of greywater resulting from the ablution process for all 370 mosques amounted to about 460,051 m^3/year. These are huge quantities that could be one of the strategic solutions to preserve the city's water reserves. However, at present, it drains into the sewage system and from there into the sea. The study also presented some recommendations that would make the most of ablution water in the city.

Key Words:
- **Greywater**
- **ablution water,**
- **mosques,**
- **Mukalla city.**
- **Yemen**

الملخص:

استهدفت الدراسة تقدير كميات المياه الرمادية الناتجة عن عملية الوضوء في مساجد الدراسة (18) وفي جميع مساجد مدينة المكلا. ومعرفة نسبة الأشخاص الذين يستخدمون مياه المسجد في عملية الوضوء، ومعرفة كميات المياه التي يستخدمها كلُّ مصلٍّ. أجريت الدراسة في فترات زمنية منفصلة من عام 2008 حتى عام 2022. وتم استخدام المسح الميداني والقياسات اللازمة لإجراء هذه الدراسة. وأظهرت الدراسة أن 32% من الداخلين لأداء الصلاة في مساجد الدراسة استخدموا مياه المساجد لعملية الوضوء. وبلغ متوسط كمية الماء التي استخدمها الفرد في الوضوء حوالي 4 لترات للصلاة الواحدة، أي بمعدل 20 لترًا لجميع الصلوات في اليوم. كما أظهرت الدراسة أن الكميات التقديرية للمياه الرمادية الناتجة عن عملية الوضوء في مساجد الدراسة لـ (18) بلغت 7924.8 م3/ شهر أو 95097.6 م3/ سنة. وأظهرت التقديرات والحسابات أن الكميات التقديرية للمياه الرمادية

الكلمات المفتاحية:
- المياه الرمادية.
- مياه الوضوء.
- المساجد .
- مدينة المكلا.
- اليمن

	الناتجة عن عملية الوضوء لجميع المساجد البالغ عددها 370 مسجدًا بلغ حوالي 460051 م3/سنة. وهي كميات كبيرة يمكن أن تكون أحد الحلول الاستراتيجية للحفاظ على مخزون المدينة المائي، وفي الوقت الحاضر تصب في شبكة الصرف الصحي ومنها إلى البحر. كما قدمت الدراسة بعض التوصيات التي من شأنها الاستفادة من مياه الوضوء في المدينة.

Introduction

The Arab world is facing a big problem represented by the scarcity of water. In recent years, the per capita proportion of fresh water decreased from 2,000 cubic meters annually in 1960 to 500 cubic meters in 2011. The increasing shortage of water in the Arab world is due to several reasons, including: the great demographic growth, the lack of water reserves (only 7% of the global reserves), the lack of precipitation, and the lack of surface water (less than 1% of the running water), and also due to the hot climate that increases the rates of evaporation of surface water [1].

Yemen is one of the countries suffering from water scarcity. It has limited resources and does not meet the increased consumption of water for all purposes. And what makes matters worse is the depletion of these resources for purposes that do not serve development, but rather are destructive to humans and the environment, such as planting the Qat tree that Yemen is famous for, where the numbers are very frightening in this regard. The water consumption to cultivate Qat tree is estimated at about (800) million cubic meters annually, while the per capita share of water is slightly more than 100 cubic meters per year, which, compared to the global scale, is very far from the necessary minimum or what is known as the water poverty line of 1000 cubic meters per year [2], and if long-term solutions, as well as quick, urgent and short-term measures to reduce the depletion of water resources are not taken, the country will face a big problem in the near future.

The international expert Asit Biswas (Nobel Prize winner for water in 2006) said: "The world does not face water scarcity, we have plenty of water to meet everything we need, but we manage water very poorly" [3]. It is clear from these wonderful words that we have to find useful solutions for water recycling, such as greywater, including ablution water which is estimated at more than 32 billion liters per day in Muslim countries, and large quantities of this water end up going to the public sewage network and from there to the seas without benefiting from it [3].

Greywater could be one of the long-term strategic solutions for Yemen to reduce the huge pressure on the current water sources. Greywater is water of lower quality than potable water, but higher quality than black water (wastewater and toilet water) [4]. For this reason, greywater reuse is gaining attention worldwide due to the lack of raw water suitable for urban uses. As a result, countries with less water resources, such as Australia, Singapore and Middle Eastern countries, have begun to treat wastewater for various reuse purposes [5].

Ablution (Wudu) is a mandatory religious routine for Muslims that is repeated several times daily for prayers and other deeds, and at the same time, conservation of water is a religious and national obligation, especially with the lack of water resources [6]. In

Yemen, for example, the quantities of ablution water produced by more than 75 thousand mosques are estimated at about 2277 million cubic meters annually [7]. The process of separating greywater from black water in homes may be costly and require additional plumbing work. Whereas in mosques, there are places designated for ablution, so greywater is directly separated from black water [8].

The process of recycling ablution water is not new. Many studies have been conducted around the world, especially in Islamic countries, to make the most of greywater, including ablution water, and many of these studies showed good results. The study conducted by Prathapar *el al*., (2006) found that 80% of the water used in Omani homes is greywater [8]. In Saudi Arabia, ablution water was used for the purpose of discharging waste in mosques and schools instead of consuming the water of the public network [9]. Khanbash & Al-Eaydrus (2004), presented positive results of the study on the use of ablution water to irrigate agricultural lands, especially Sidr trees (*Rahmanus*) in Wadi Hadhramout- Yemen [10]. Abdul Salam (2007) presented a study that indicated the success of the project of reusing ablution water to irrigate trees in Aden [11]. And the same idea of reusing ablution water was implemented in the cities of Taiz and Hodeidah to irrigate green spaces [12]. There are also other studies [13, 14, 15, and 16] that deal with ways to treat ablution water and how to get benefit from it.

There is a significant shortage of water supply in Mukalla city due to a decrease in the quantity of water extracted from the Al-Ghail city basin. For years, this basin has been providing Mukalla city with water on demand. The main reason of decreasing of water quantities of the basin is due to: population increase, excessive use of water for various purposes such as irrigation of green spaces, and lack of rainfall. This problem clearly appeared after decorating the city and creating many green spaces of the streets, roads, and parks in 2005 (Al-Rayyan Airport Road, Khalaf Road, Mukalla Khor, 60th Street, and public parks in the city). The Al-Rayyan airport road, which was estimated to have an area of around 400000 m^2, consumes approximately 298000 m^3 every year [17]. Regrettably, these enormous amounts of water were taken out of the public drinking water system.

The issue of alleviating the enormous pressure on water supplies and reducing its unjust depletion for various purposes in light of its scarcity is considered one of the challenges for which strategic solutions must be found, including making the most of the greywater resulting from the ablution process in the mosques of the city of Mukalla. As a result, the objectives of this study are as follows:

- Knowledge of the actual quantity of water consumed in the ablution process per person per day.
- Estimation of the water quantities resulting from ablution processes (Wudu) of the mosques in Mukalla city.

MATERIALS AND METHODS

Study Area

Mukalla city, the capital of Hadhramout Governorate, is located in the southeast of the Republic of Yemen on the Arabian Sea coast, and about 620 km away from the capital Sana'a (Fig-1). The population of the city and its suburbs, according to the 2004 census, is about 201,383 [18]. And if we take into account the population growth rate in Hadhramout Governorate (3.08%) without other factors such as displacement from internal conflict areas or reverse migration from the Gulf countries, the population of Mukalla city may increase to more than 360,000 people in approaching years. Mukalla's original inhabitants are from urban areas and are considered a relatively civilized society, compared to the rest of the cities of Yemen, whose majority are Bedouins and rural areas [18]. The city's weather is hot in summer and mild in winter, with semi-seasonal rainfall. Mukalla city is distinguished by the presence of a large number of mosques, which was estimated to be about 370 mosques until the end of December 2022 [19].

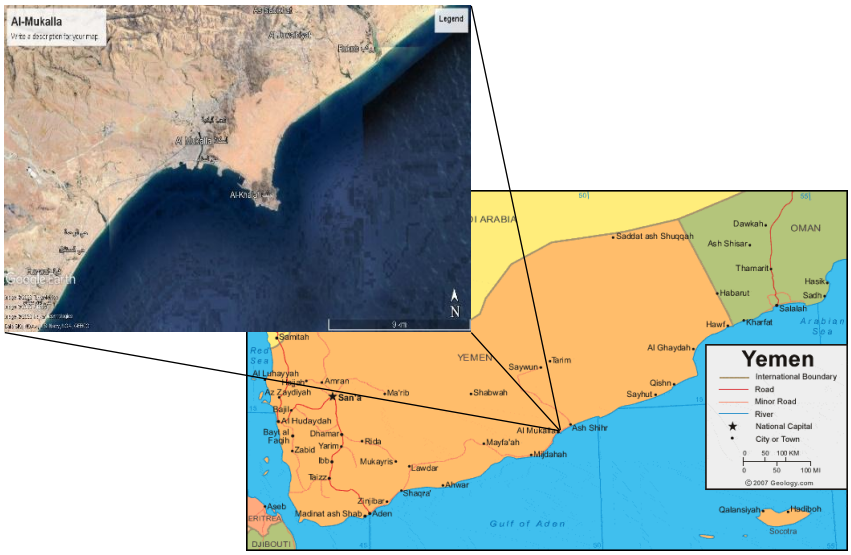

Figure- 1: Map of the Mukalla city [20, 21]

Data collection

Eighteen (18) mosques in the city of Mukalla were targeted to implement this study (Table-1), through stages and at different time periods, from 2008 to 2022. These mosques were selected due to: first, they covered all areas of the city, and second, some of them have a large capacity for worshippers due to the presence of religious centers. The methodology of this study relied on a field survey. All measurements were taken for each mosque separately and for the five prayers. The mechanism for calculating the number of worshipers was based on calculating the numbers worshipers entering the mosque immediately after the call to prayer and the numbers of who perform ablution in the mosque.

In order to calculate the quantities of water used in the ablution process, only three mosques were chosen: Al-Sharj, Al-Rawdah, and Al-Saddig. The reason for choosing these mosques lies in the fact that they represent major gathering centers for worshipers, and they are situated in different regions in the city. The mechanism was as follows: a bowl was placed and after the person completed ablution, the amount of water was measured. For each mosque, 20 measurements were taken.

Table-1: Mosques names and their location in Mukalla city

N	Mosque name	Coordinates		Location
		Latitude	Longitude	
1	Al-Rawdah	**14° 31.740' N**	**49° 8.190' E**	Old Mukalla
2	Omar	**14° 31.844' N**	**49° 8.085' E**	Old Mukalla
3	Al-Najem	**14° 32.576' N**	**49° 7.630' E**	Bajuman
4	Warasmah	**14° 31.938' N**	**49° 7.421' E**	Al-Sharj
5	Al-Sharj	**14° 32.110' N**	**49° 7.529' E**	Al-Sharj
6	Al-Safa	**14° 32.631' N**	**49° 7.461' E**	Al-Sharj
7	Al Yasir	**14° 33.068' N**	**49° 6.996' E**	Al-Galilah
8	Al-Shuhada	**14° 32.921' N**	**49° 7.598' E**	Al-Dees
9	Khalid ibn Al-Walid	**14° 33.237' N**	**49° 7.908' E**	Al-Dees
10	Bahr Alnuwr	**14° 29.472' N**	**49° 2.770' E**	Almasakin- Fuwa
11	Al- Marwah	**14° 29.383' N**	**49° 3.022' E**	Fuwa
12	Moaz bin Jabal	**14° 29.173' N**	**49° 2.389' E**	Almasakin- Fuwa
13	Al-Saddiq	**14° 29.290' N**	**49° 2.548' E**	Almasakin- Fuwa
14	Othman	**14° 28.310' N**	**49° 1.912' E**	Inb Sina-Fuwa
15	Altaqwaa	**14° 29.645' N**	**49° 3.250' E**	Fuwa
16	Al-Sheikh Abu Bakr	**14° 29.761' N**	**49° 2.566' E**	Almasakin-Fuwa
17	Alrahman	**14° 28.890' N**	**49° 2.018' E**	Old Fuwa
18	Al-Barkah	**14° 29.452' N**	**49° 2.514' E**	Almasakin-Fuwa

RESULTS AND DISCUSSIONS

1. Calculating of the total number of worshipers and the percentage of those who used water for the ablution process in the mosques under study.

Through the mechanism adopted to calculate the number of worshipers and the number of people performing ablution of the 18 mosques (Table-2), it was found that the largest number of worshipers were present in the Al-Sharj Mosque, 5915 worshipers/ five prayers/ a day, i.e. an average of 1183 worshipers/ for a prayer. The reason for this is due to that the Al-Sharj mosque is located in a densely populated area and also has been considered one of the biggest mosques of the city. The smallest mosque was Sheikh Abu

Bakr which accommodated about 880 worshipers/ five prayers/ a day, with an average of 176 worshipers/ for a prayer. It also turned out that the total number of worshipers who attended prayer at all 18 mosques were about 40,282 persons/ five prayers/ a day, with an average of 450 persons/ five prayers/ a day. It was also found that about only 32% of worshipers used water for ablution process. Compared to the study conducted by Abu Rozaiza (2002) in Saudi Arabia, this percentage ranges between 13% in residential areas to 40% commercial areas [9].

Table 2: Statistics obtained during the field survey for the study

N	Mosque name	Average worshippers/ day (Aw)	Total worshippers for all prayers/ day	Percentage of those who performed ablution, %	Number of those who performed ablution
1	Al-Rawdah	834	4173	37	1544
2	Omar	899	4497	28	1259
3	Al-Najem	260	1300	31	403
4	Warasmah	369	1745	24	419
5	Al-Sharj	1183	5915	35	2070
6	Al-Safa	258	1290	37	477
7	Al Yasir	359	1795	26	467
8	Al-Shuhada	779	3897	35	1364
9	Khalid ibn al-Walid	328	1640	40	656
10	Bahr Alnuwr	294	1470	40	588
11	Al- Marwah	211	1053	25	263
12	Moaz bin Jabal	238	1090	40	436
13	Al-Saddiq	589	2945	33	972
14	Othman	382	1912	28	535
15	Altaqwaa	258	1290	30	387
16	Al-Sheikh Abu Bakr	176	880	28	246
17	Alrahman	458	2290	35	802
18	Al-Barkah	220	1100	29	319
		450	**40282**	**32**	**13208**

2. Calculating of the quantities of water used for ablution

The process of measuring the amount of water used for ablution per person was carried out in three main mosques: Al-Sharj, Al-Rawdah, and Al-Saddig. Twenty measurements for each mosque were taken (Table- 3). It was found that the amount of water used in the ablution process varies from person to person. The lowest measure was 1.7 liters/ person/ prayer at Al-Saddig, while the largest amount of water used was about 6 liters/ person/ prayer at Al-Sharj. It was found that the average amount of water used per person is about 4 liters / person/ prayer, i.e. 20 liters/ person/ five prayers/ a day. It should be indicated that the amount of water used for ablution might have been more than the average (4 liters/ person), since the process of placing the vessel under the tap, psychologically, might be an obstacle that makes the person performing ablution more cautious and not take his time and unnecessary water quantity for the ablution process. According to a study conducted by Abu Rozaiza (2002), the average ablution water amount was determined as 2.5–4.5 L/ person in some masjids, schools and governmental buildings. But the researcher found that this amount increases to 5 L in the two holy Harams and 6–7.5 L/ person in A'rafah and Muzdalifah respectively during the Hajj season

[9]. There are many studies that dealt with the amounts of water used for the ablution process in many parts of the Arab and Islamic world. Quantities varied between 2 to 9 liters per person [22, 23, 24].

In fact, the average ablution water revealed by this study for each worshiper is very large. The Prophet (God's blessing and peace be upon him) determined the amount with which a Muslim should perform ablution and bathe. In the authentic hadith, the Prophet (God's blessing and peace be upon him) "used to wash with a saa (صاع)', and perform ablution with a mad, (مد)". Saa' is equal to (2.75 liters of water), and a mad is equal to (0.687 liters of water) [25].

Table -3*: Measuring of the amount of ablution water for each person in the selected mosques*

Al-Saddig				Al-Rawdah				Al-Sharj			
N	liters	N	liters	N	liters	N	liters	N	liters	N	liters
1	**3.6**	11	**5.4**	1	**3.6**	11	**4.5**	1	**2.5**	11	**3.9**
2	**4.7**	12	**4.9**	2	**4.9**	12	**3.7**	2	**4.5**	12	**4.7**
3	**4.8**	13	**4.6**	3	**5.6**	13	**2.9**	3	**5.2**	13	**4.2**
4	**3.4**	14	**3.2**	4	**3.6**	14	**3.5**	4	**1.7**	14	**4.6**
5	**2.7**	15	**4.7**	5	**4.7**	15	**1.9**	5	**4.6**	15	**4.7**
6	**1.8**	16	**3.5**	6	**3.6**	16	**1.9**	6	**3.5**	16	**5.6**
7	**3.0**	17	**6.0**	7	**5.5**	17	**4.8**	7	**4.5**	17	**4.7**
8	**5.2**	18	**3.8**	8	**5.0**	18	**4.2**	8	**3.5**	18	**4.0**
9	**3.8**	19	**4.7**	9	**4.8**	19	**3.4**	9	**5.3**	19	**2.0**
10	**2.5**	20	**4.8**	10	**4.0**	20	**2.5**	10	**5.5**	20	**3.9**
Average	**4.2**			**3.9**				**4.1**			
Mean± D	**4.05**										

3. Estimating the quantities of generated water of the ablution process from mosques under study in Mukalla city

For the mosques under study, the process of knowing the average amount of water used in the ablution process (20 liters per person/ a day), as well as the percentage of worshipers (32%) who performed the ablution process in the mosques of the study, the possibility of calculating the estimated quantities of the ablution water that were consumed during the day in the mosques under study was calculated using equation (1). It was found that the estimated quantity of water produced from ablution process from the 18 mosques under study (Q_{sm}) was about 264.16 m^3 /day or about **7924.8** m^3 /monthly.

$$Q_{sm} = W_a + N \qquad (1)$$

Where:

- ***Qsm: The estimated amount of water generated from the ablution process in the mosques under study per day. (264.16 m^3 /day or 7924.8 m^3 /monthly)***
- ***Wa: The average amount of water used in the ablution process (20 liters/* person/ day**).
- ***N***: The number of worshipers who used water in the ablution process in the mosques under study **(13208 persons)**.

4. Estimating the quantities of generated water of the ablution process from all mosques in the Mukalla city

Statistical information obtained from the Statistics department at the General Corporation for Water and Sanitation in Mukalla indicates that the number of mosques in Mukalla and its suburbs in the end of 2022 reached 370 mosques [19]. Figure 2 shows the quantities of water consumed from the public pipeline for all mosques in the city of Mukalla during the year 2022, which reached about **203082** m^3. It is noted that the lowest consumption was in November 15195 m^3, while the highest consumption was in May reaching 18864 m^3. Average consumption was around 17,000 m^3 monthly.

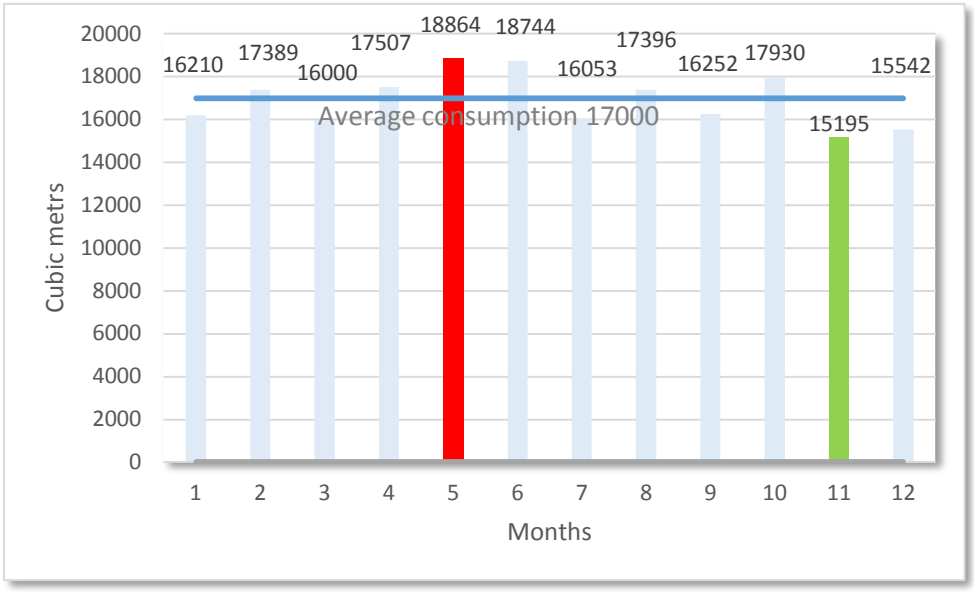

Figure 2: Quantities of water taken from the public network for mosques in the city of Mukalla during 2022 [19]

It was found above in (Table-2) that the average number of worshipers (*Aw*) a day for the mosques under study were estimated to be 450 worshipers / a day, and only 32% of this number used water for the ablution process. Thus, we were able to calculate the estimated quantities of water ($Q_{(e.t)}$) produced for ablution water from all the mosques in the city of Mukalla, by equation (2 and 3).

$$Q_{cm} = A_w * P * W_a * (M_{sm} - M_{sm}) \qquad (2)$$

$$Q_{(e.t)} = Q_{sm} + Q_{cm} \qquad (3)$$

Where

- ***Qcm***: Estimated quantities of water generated from the ablution process of the city mosques (excluding the mosques of the study) per day, (**30412.8 m^3/ month).**
- ***Aw***: The average number of worshipers/ day. (450 persons).
- ***P***: Percentage of those who performed ablution. (32%).

- $\boldsymbol{Wa}$: The average amount of water used in the ablution process (20 liters/ person/ day).
- $\boldsymbol{Mcm}$: The number of all city mosques. (352 mosques).
- $\boldsymbol{Msm}$: The number of mosques under study. (18 mosques).
- $\boldsymbol{Qsm}$: The estimated amount of water generated from the ablution process in the mosques under study per day. **(7924.8 m^3/month).**
- $\boldsymbol{Q(e.t)}$: Estimated total quantities of water generated from mosques in the city in general. **(38337.6 m^3/ month).**

The estimated total quantities of generated water from city's mosques were about **1278** m^3/day or **38338** m^3/ month or **460051** m^3/ year. These huge quantities of water are considered one of the strategic solutions to preserve water reserves and they can for example, irrigate the green areas in the city, but unfortunately, they are still going to the sea.

A question may arise: How is the amount of water consumed by the city's mosques approximately 203082 m^3/ year, while the only output of ablution water (460051m^3/year) is much more than the quantities taken from the public water system? The answer is that most of the city's mosques have private wells that they rely on mainly as a source of water. This explains the huge quantities resulting from the ablution process, which far exceed those taken from the public water system. It should also be noted here that the estimated quantities of water resulting from the ablution process in this study did not take into account the quantities of water used during prayers held on various religious occasion.

Nowadays, there is no accurate statistical information about the quantities of water that are consumed to irrigate the green spaces such as the Airport Road (Al Rayyan line), Khalaf Road, Khor Mukalla, Sixty Street, and public parks scattered in the city. However, it be pointed that in 2013, to irrigate about 400,000 m2 of the green area Airport Road (Al Rayyan line), 297,324 m3 of water that was taken from the public network was consumed [17].

Certainly, it is necessary to take advantage from outputs of the ablution water to irrigate the green areas in the city, as it has been implemented in many Yemeni cities such as Aden [11], Taiz, Al-Hodeidah [12], Wadi Hadhramout [10], and other Arab cities [9, 8].

If we take the estimated total quantities of ablution water of the all Mukalla's mosques, as well as the required water to irrigate the green areas (for example, Al-Rayyan Road), and the consumed water by the mosques from the public system (Figure-3), it is clear that ablution water can play a major role in preserving the water reserves for future generations by covering all the city's water needs for example, to irrigate green areas or even might use for other purposes.

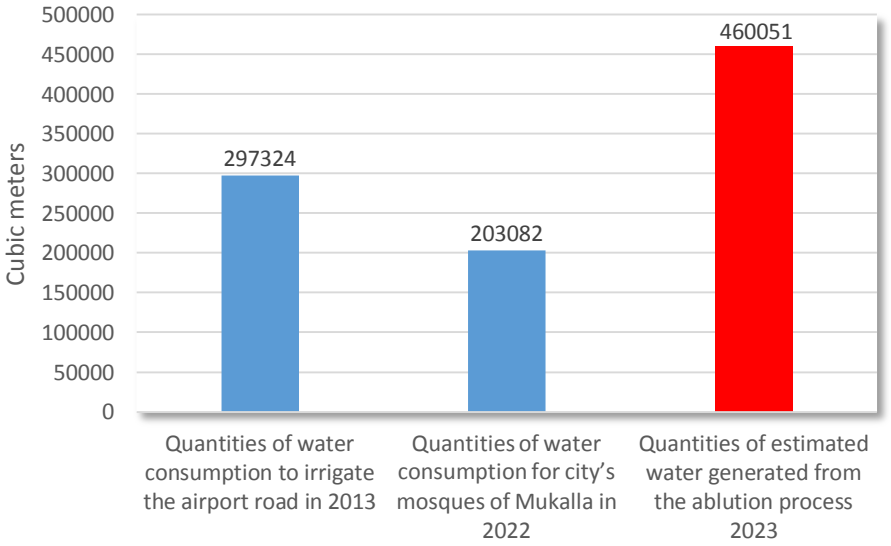

***Figure 3**: Estimated quantities of ablution water for mosques in the city of Mukalla and how they play a role in preserving the city's water reserves.*

Conclusions and recommendations:

1. The study concluded that the average amount of water consumed in the ablution process amounts to about 4 liters/person/per prayer, i.e. 20 liters/person/a day.
2. The study concluded that the percentage of those who enter the mosque and perform ablution is about 32% of the number of worshipers who enter to pray.
3. The study showed that the estimated quantities of greywater resulting from the ablution process in the 18 mosques under study were 7924.8 m^3 /monthly or 95097.6 m^3 / year.
4. Mathematical calculations showed that the estimated quantities of greywater resulting from the ablution process for all mosques (370mos.), were about 460051 m^3/ year.
5. It has been shown that many experiments in the country and the region to make use of greywater resulting from the ablution process were successful, so the study recommends local authorities and concerned organizations to make maximum use of ablution water, for example to irrigate green spaces in the city.
6. The study recommends using smart faucets to reduce the amount of water used during ablution.
7. The study recommends separating greywater (ablution water) from black water (bathroom water) during the construction of modern mosques to irrigate the green spaces of the mosques themselves and the areas near them.

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