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Evaluation of the Contribution of Domestic Cooling Systems to the Reuse of Extracted Atmospheric Moisture to Support Agricultural Water

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Abstract
This study was conducted to evaluate the quantitative and qualitative aspects of condensate water generated by household air conditioners and its potential use as an alternative source for irrigating home crops. The study was conducted at 12 stations within Baghdad during the summer of 2023. Water samples were collected daily for 8 hours, at a rate of four samples per month. According to the findings, the quantity of condensed water ranged from 1.31 liters in June to 2.08 liters in August, the latter representing the maximum value. A positive correlation was found between the amount of water produced and temperature and relative humidity, a correlation coefficient of R=0.688 for temperature and a p-value of 0.058803, and R=0.659 for humidity with a p-value of 0.075266 at $p<0.05$. A qualitative assessment of water quality was conducted through measuring pH, (6.5 to 7.79), total dissolved solids (TDS: 20–483 mg/L), and electrical conductivity (EC: 38–1119 µS/cm). Chloride ion concentrations and total hardness ranged from 0.01 to 0.06 mg/L and 30 to 70 mg/L, respectively. Sodium concentrations fluctuated between 0.9 and 37.8 mg/L, while calcium and magnesium each averaged 36 mg/L. Lead levels ranged from 0.003 to 0.056 mg/L, and iron concentrations from 0.07 to 28 mg/L.The study concluded that the air conditioning water can be used to irrigate domestic crops in terms of quantity, and its chemical properties are generally consistent with local and international specifications, except for its lack of essential nutrients necessary for plant growth.

Keywords: Domestic Conditioner, Irrigation, condensing water, heavy metals

تقييم مساهمة انظمه التبريد المنزلي في اعادة استخدام الرطوبة الجوية المستخلصة لدعم المياه الزراعية

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الخلاصة
اجريت هذه الدراسة لغرض التقييم الكمي والنوعي للمياه المتكثفة الناتجة عن أجهزة التكييف المنزلية،

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وإمكانية استخدامها كمصدر بديل لري المزروعات المنزلية. تم انجاز الدراسة في 12 محطة داخل مدينة بغداد خلال أشهر الصيف لعام 2023، حيث جُمعت عينات المياه يوميًا لمدة 8 ساعات، بمعدل أربع عينات شهريًا. أظهرت النتائج أن كمية المياه المكثفة تراوحت بين 1.31 لتر في حزيران وسجلت اعلى قيمه 2.08 لتر في اب. كما لوحظ وجود علاقة ارتباط طردية بين كمية المياه الناتجة ودرجات الحرارة والرطوبة النسبية، اذ كان معامل الارتباط 0.688 مع الحرارة حيث كانت قيمه P (P = 0.058803) و0.659 مع الرطوبة حيث كانت قيمه (P =0.075266).تم اجراء تقييم نوعي لجودة المياه من خلال قياس درجة الحموضة pH التي تراوحت بين(6.5 و 7.79)، والمواد الصلبة الذائبة الكلية (TDS) التي تراوحت بين (20 و483 ملغم/لتر)، والتوصيلية الكهربائية (EC) التي تراوحت بين (38 و1119 ميكروسيمنز/سم). تراوحت تركيزات أيون الكلوريد والصلابة الكلية بين (0.01 و0.06 ملغم/لتر)(30 و70 ملغم/لتر) تباعا. سجل الصوديوم تراكيز من 0.9 إلى 37.8 ملغم/لتر، والكالسيوم والمغنيسيوم بمعدل 36 ملغم/لتر لكل منهما. أما الرصاص فتراوح بين 0.003 و0.056 ملغم/لتر، والحديد بين 0.07 و2.8 ملغم/لتر.خلصت الدراسة إلى أن مياه التكييف يمكن استخدامها لري المحاصيل المنزلية من حيث الكمية، كما أن خصائصهاالنوعية متوافقة عمومًا مع المواصفات المحلية والدولية، باستثناء انه النبات لايجد في هذه المياه ما يحتاجه من العناصرالغذائية الأساسية اللازمة لنموه.

1. Introduction

Water is essential for life and is used for domestic, agricultural and consumer needs. Key development factors include its availability over time [1].

It has been reported that condensate water can be reused in many processes, such as irrigation and factory cooling towers, and therefore should not be considered waste. Many regions of the world have used air conditioning systems, including Baghdad, the capital of Iraq, which is characterized by notably high temperatures. The use of condensate water from these systems has been proposed as a water-saving methods, both in large buildings and in homes [2]. The WHO states that physical, chemical, biological, and visual characteristics all affect water quality [3]. Even though there are specific concerns about the potential health risks associated with using condensate water from air conditioners, a study carried out ten years ago in Qatar revealed that more than 6 million liters per year of condensate water may be collected from air conditioners in a building [4]. Condensate water is a viable and untapped alternative supply of water, as demonstrated in a recent experiment conducted in Qatar [5]. Additionally, some studies have examined the water is collected from a building's air conditioning system and the ongoing treatment of that water [6]. It is believed that the average amount of water used in Bangladeshi manufacturing processes for every kilogram of cloth produced is 250 to 300 gallons [7]. In Dhaka, this is equivalent to the water consumption of two people per day. According to international standards, producing 1 kg of cloth consumes approximately 100 liters of water. [8]. It is anticipated that using condensate water as an extra coolant on the condenser will lower the condensing temperature. In a previous study, it was found that the use of air conditioners with a capacity of 2 tons may produce a volume of wastewater ranging from 3.5 to 4.5 liters [9]. Water management is one of the most crucial areas that need to be cared for, protected, and maintained because it is essential the agricultural sector. Iraq is suffering from an unprecedented water crisis, despite the Tigris and Euphrates rivers running through its territory due to several factors, including neighboring countries' dam and reservoir construction projects and environmental factors, which include high annual temperatures that have affected the country's climate and reduced rainfall rates that have led to desertification, which has impacted agricultural production and sustained [10]. According to estimates, approximately 70% of the total water used in agriculture is wasted in unsustainable irrigation operations, ranging from 15% to 35%. All that information suggests using condensed water from air conditioners for agricultural uses [11]. Approximately 2,000–3,000 liters of water are required to meet an individual's daily nutritional needs; household use accounts for around

8% of global water consumption. Water uses for domestic use, industry, agriculture, irrigation, and livestock drinking are all covered in great detail [12]. Instead of taking in air from the outside, modern air conditioning systems circulate more and more cold air into the room. The cooling portion of the process condenses warmer water vapor during the freezing cycles and falls it onto a fastening plate at the bottom of the component. Since this intimate air is continuously humidified, the vapor must be sent externally, typically through a gutter opening [13]. Changing temperatures affect the air's ability to become saturated with water vapor. It's possible to store more water vapor at higher temperatures. The amount of water vapors that can be held in the air reduces with decreasing temperatures. It was noted that the decrease in surface temperature below the dew point contributes to the transformation of water vapor in the air into water droplets after condensation. A diagram of the process for producing water in an air conditioner is shown in Figure 1 [14, 11,13].

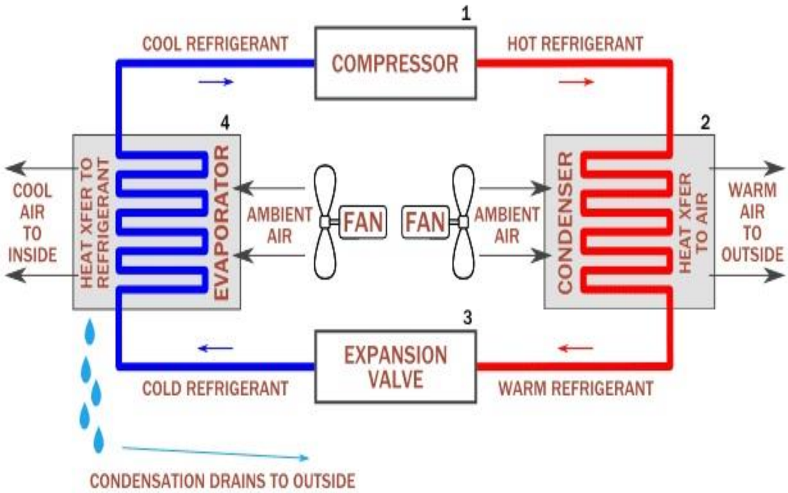

Figure 1: air conditioning (AC) unit with method of water creation [14].

The research focuses on analyzing the feasibility and potential of using steam condensation water in domestic air conditioning units.as an alternative source for plant irrigation, within the framework of the search for sustainable solutions for water resources or other uses by evaluating this water quantitatively and qualitatively, then comparing it with established irrigation water quality standards. The research also aims to identify potential approaches to environmental water management, particularly in the context of seeking sustainable solutions in some areas suffering from water scarcity.

2. Materials and methods

2.1 condensed cooling water samples

Air conditioning AC condensate water samples were collected from twelve sites of Al-Karkh and Al-Rusafa districts in Baghdad city, with six different sites for each in Al-Karkh (Mansour , Ghazaliya, Amireayah, Bayaa, Dora, and Al Shurta),while in Al-Rusafa district (Ghadeer, Palestine street,Shaab,Qahera,Adhamiyah, near Utaifiyah), as shown in Figure 2 [15] . The GPS coordinates for each of the 12 study sites are shown in Table 1[15]. Baghdad has a dry desert climate (Köppen BWh), with an average annual temperature of 23.3 °C, and highs of around 44 - 45 °C in July and August. The annual humidity rate is approximately 43.6%, with the highest levels in winter (~71%) and the lowest in summer (~22%) [16].

Water samples were collected from homes at stations during the summer months, from June to September 2023, a period characterized by high temperatures and the frequent use of cooling systems. These conditions enabled the collection of larger and more consistent volumes of condensate water, making it easier to estimate and analyze due to the high temperatures in Baghdad. All air-conditioning units used in the study were 2-ton capacity systems, representing various commonly available brands.

Figure 2: A map shows the study stations [15]

Table 1: The GPS coordinates for the study stations [15]

Study Stations	coordinates
Mansour	33°19'03"N 44°21'11"E
Ghazaliya	33°20'32"N 44°16'53"E
Al-A'amiriya	33°17'56"N 44°17'24"E
Bayaa	33°16'05"N 44°20'41"E
Dora	33°15'26"N 44°23'40"E
Al Shurta	33°15'08"N 44°24'10"E
Ghadeer	33°18'53"N 44°28'20"E
Falastin Street	33°22'09"N 44°24'13"E
Sha'ab South	33°24'51"N 44°24'05"E
Qahira	33°22'49"N 44°23'48"E
Adhamiyah	33°22'07"N 44°21'42"E
Near Utaifiyah	33°21'11"N 44°22'03"E

2.2 Quantitative estimation

The amount of water produced per 8 hour/day (12AM to 6PM) from each air conditioner was estimated separately by using 20-liter plastic containers to collect water samples from the drain pipe of the air conditioner's outdoor unit and then estimating them using a volumetric flask (1000 ml)[11]. Four samples of condensate water were collected monthly for each of the studied stations during June, July, August, and September. Also the mean of these four samples was calculated. Because cooling systems depend in their production of condensed water on the extent to which they are affected by temperatures and humidity outdoor homes, temperatures and humidity were measured during the process of collecting water samples by using portable device (TemtopLKC-1000S+air quality detector/IAQ monitor) and finding the average temperature and humidity rate for each of the 12 sites studied.

2.3 Qualitative estimation

In situ, the physicochemical characterization of the condensed water samples was conducted using a multi-parameter handheld device (Model: SM 802 PH/EC/TDS meter), which is enabling real-time assessment of hydrogen ion concentration (pH), levels of electrical conductivity index (EC), and total dissolved impurities (TDS) concentration at sample collection points. Electrical conductivity (EC) was specifically utilized as a surrogate measure for the salinity levels of the samples, as it correlates with the concentration of dissolved ionic species [17]. The other tests were performed in the laboratories of Baghdad University and compared with the Iraqi specifications for water use according to the standard. Examinations were conducted following the World Health Organization guidelines [18, 19].To evaluate chloride ion concentrations (Cl^-), a volumetric method was employed utilizing potassium chromate (K_2CrO_4) as the indicator and a 5% silver nitrate ($AgNO_3$) solution as the titrant. A 10 mL aliquot of K_2CrO_4 was added to 5 mL of the sample and twenty milliliters of purified (distilled) water in a 200 mL glass container. Silver nitrate ($AgNO_3$) was employed as the titrant in the titration procedure until the sample changed from a yellow to a red coloration. The chloride ion concentration was then calculated by multiplying the volume of titrant used by its normality, dividing the product by the sample volume, and finally converting the result to mg/L by multiplying by 1000[20].The total hardness (TH) was assessed by using titration with ethylenediaminetetraacetic acid (EDTA) [19].

To quantify sodium ion concentrations (Na^+), a flame photometry technique was used, which is based on the principle of atomic emission spectroscopy. During examination, water samples were introduced into the flame via beakers placed below the detection probe, and sodium concentrations were directly recorded [18]. For the quantification of magnesium ions (Mg^{2+}), the concentration of calcium ions (Ca^{2+}) was first determined using a complex metric titration with ethylenediaminetetraacetic acid (EDTA). Afterwards, the Mg^{2+} concentration was determined by deducting the previously measured calcium content from the overall levels of divalent cations (Ca^{2+} + Mg^{2+}).In this procedure, a precise portion of 5 mL of condensed water sample was mixed with 20 milliliter of distilled water and 10 mL of buffer solution. To ensure accuracy, four drops of Eriocrom Black T indicator were added to the mixture, and the sample underwent titration using with a 0.01molar solution of EDTA until a visual endpoint was indicated by the color change from red to blue-green was observed, indicating the endpoint of the titration which is a reliable indicator of the occurrence of divalent cations, notably (Ca^{+2}) and (Mg^{+2}) [19].To measure heavy metals like lead (Pb) and iron (Fe) mg/l in water, samples must first undergo acid digestion as described by Kováčová [17]. This step breaks down interfering substances and converts metals into a detectable form for analysis using techniques atomic absorption spectrophotometry (AAS).

Statistical Analysis

To study the impact of different variables on the study indicators and data analysis, the System (SAS, 2018) for Statistical Analysis was employed. To make comparisons between averages, aT- test was applied to find differences between the Karkh and Rusafa districts. The index of correlation (R) and a p-value (Probability value) were also estimated to determine if there was a correlation between the amount of water collected from air conditioners and temperatures on the one hand and relative humidity on the other hand [21].

3. Results and discussion

Table 2: Different month's effects on the average amount of condensate (AC) water with average of temperature and relative humidity

Months	**June**		**July**		**August**		**September**		**P value**
Stations	Al-Karkh district	Rusafa district	Al-Karkh district	Rusafa district)	Al-Karkh district air	Rusafa district	Al-Karkh district	Rusafa district	
ACwater average±SD	1.36±0.16	1.31±0.19	1.68±0.21	1.88±0.14	1.80±0.17	2.08±0.24	1.71±0.26	1.68±0.11	p>0.05 NS
Temperature C° average±SD	43.44±2.51	41.08±3.61	44.5±1.52	45.31±2.15	45.63±3.22	45.80±2.01	41.58±1.74	41.90±1.42	p>0.05 NS
Relative humidity RH% average±SD	29±2.15	29±3.25	28±2.51*	36±2.42*	37±1.14*	33±2.31*	35±2.72	33±1.96	p<0.05

*significant at p<0.05 ,NS: Non-Significant

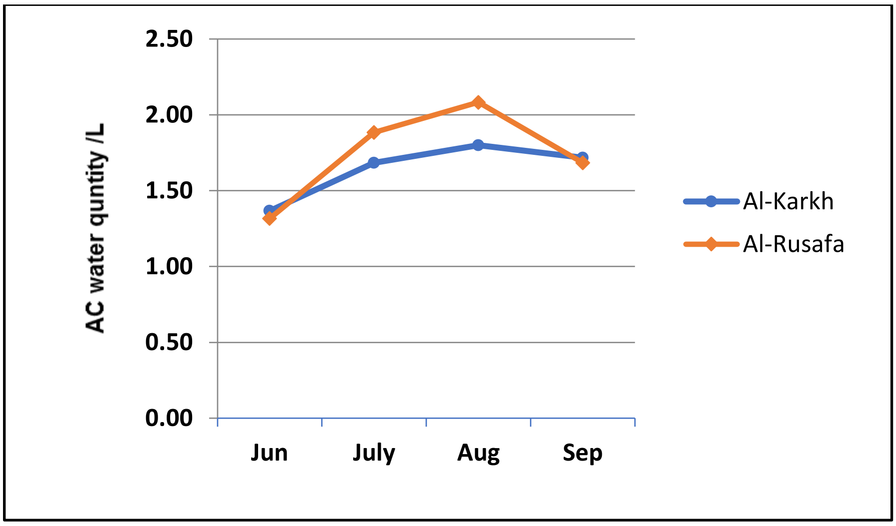

Figure 3: ACwater quantity during summer months in Al-Karkh and Rusafa district

The results of the current research, as revealed in Table 2 and Figure 3, show that the water production obtained by air condensation was highest in August (2.08±0.24), followed by July 1.88±0.14, and this was observed on both sides of Karkh and Rusafa. This is due to the rise in temperature to 45.80±2.01 °C on the Rusafa side, in addition to the increase in humidity to 37±1.14. Statistically the difference between months is considered not significant at $p > 0.05$ for water quantity and temperature, while for relative humidity, a p-value under 0.05 suggests that the differences are statistically highly significant, especially in July, and very statistically significant ($p < 0.05$) in August. An increase in temperature and humidity outside the house contributes to increased water production from air conditioners. This result is consistent with what the researchers have reached [22]

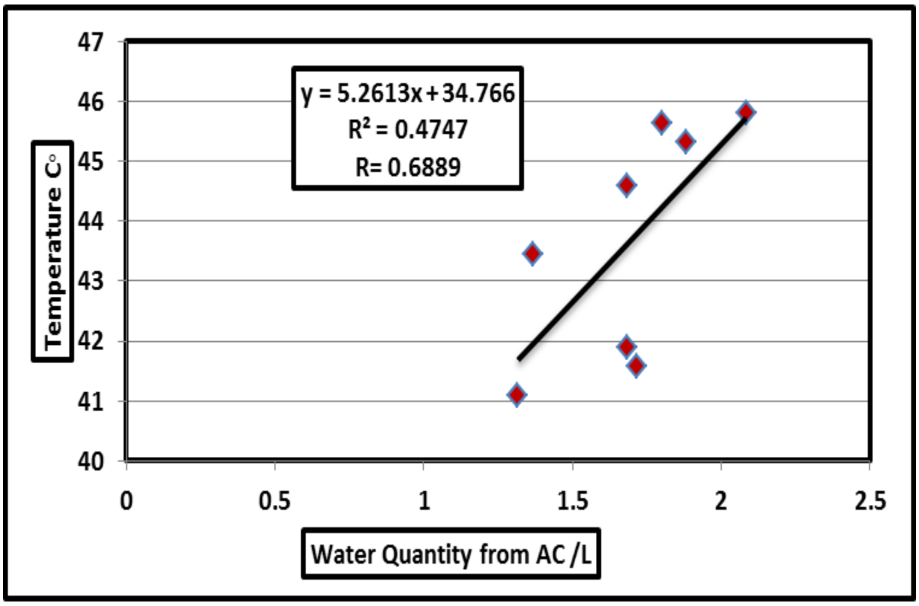

Figure 4: Correlation between the amount of water and temperature.

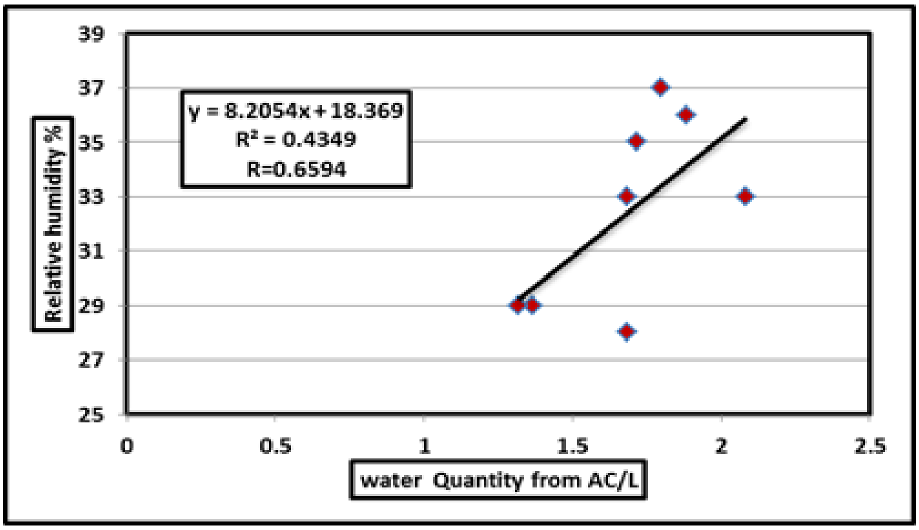

Figure 5: Correlation between the amount of water and relative humidity

The results in Figure 4 indicate a noticeable positive correlation observed between the amount of water generated during the operation of the air conditioner and temperature (R=0.6889), with the (p-value) of 0.058803. This difference is considered not statistically significant at $p<0.05$. Also, the correlation between the amount of water and relative humidity was moderately positive (R=0.6594), with the p- value equal to 0.075266; this difference is considered to be not quite statistically significant at $p<0.05$, as shown in Figure 5.Previous study have shown that outdoor temperatures and relative humidity affect water production, and the amount of water produced increases in high-humidity conditions. Additionally, the amount of water produced is influenced by other things such as the age of the air conditioner, If it is new, it produces a larger amount of water, and vice versa. There is also a direct relationship between the total amount of water content produced from the external drain pipe and the total number of individuals involved indoors [22].

PH values

Upon comparison of the results of condensate AC water evaluated against the Iraqi standard specifications for the permissible limits and standard for the water quality employed for irrigation purposes, the hydrogen ion (pH) value range between lowest value 6.5, and the highest 7.79, as shown in Table 3, these values considered an acceptable as compared within the Iraqi standard specifications, which indicates 6.5 - 8.5 acceptable limits [23].

Table 3: Effect of stations and condensate (AC) water on pH and their statistical analysis

Stations	Al-Karkh district	Rusafa district	p-value
St: 1	7.79	6.72	$p<0.05$
St: 2	7.55	6.73	$p<0.05$
St: 3	7.24	6.5	$p<0.05$
St: 4	6.67	6.51	$p<0.05$
St: 5	7.30	6.60	$p<0.05$
St: 6	6.78	7.47	$p<0.05$
Mean ±SD	7.22±0.43	6.75±0.36	P=0.19711

A statistically significant differences in pH values was found between the Al-Karkh and Rusafa districts, with a p value of 0.19711.Deficiency symptoms may result from a low availability of certain metals and minerals due to a high pH (>7.0). High alkalinity frequently goes hand in hand with high pH. Acid injections or, in certain situations for acid-tolerant plants, the use of acid fertilizer can address high pH issues. Less frequently, large amounts of harmful metals, such as iron and manganese can be caused by low pH (<5.0); this is typically observed in conjunction with low alkalinity. Liming the growing medium or converting to a basic fertilizer are two solutions for low pH issues. This explains the outcomes derived from this research, including the high acidity and its effects on plants, as observed as in the above other studies [24, 25].

Electrical conductivity (EC)

As for the suitability of condensed cooling water (AC) as irrigation water, the results of Electrical conductivity ranged from 38 to 1119 µS cm^{-1}, according to Table 4. A statistically significant difference in EC values was found between Al-Karkh and Rusafa districts, with a p-value of 0.08306. The classification of Bauder and his group [26] was adopted, indicating that the values range from "nothing," meaning no harmful effects usually appear, to "some," meaning they may have detrimental effects on crops, especially sensitive ones. The classification spans from (none), indicating water is generally safe with no observable adverse effects, to (some), referring to water that negatively impacts sensitive crops.

Table 4: Effect of station and condensate (AC) water on electrical conductivity (EC) µS/cm. and their statistical analysis

Stations	**Al-Karkh district air conditioner water**	**Rusafa district air conditioner water**	**p-value**
St: 1	474	76	$p<0.05$
St: 2	598	46	$p<0.05$
St: 3	717	89	$p<0.05$
St: 4	80	291	$p<0.05$
St: 5	555	215	$p<0.05$
St: 6	119	38	$p<0.05$
Mean ±SD	423.83±263.49	125.83±103.11	P= 0.08306

Table 5: Dissolved salt content according to the hazard EC values (μS cm−1) of irrigation water

Hazard	Dissolved salt content EC (μS cm−1)
None – water that is generally safe for irrigation with no risk seen on plants.	750
Some – water is considered to have a negative impact on sensitive crops.	750–1500
Moderate – water that may have an impact on a wide range of crops, therefore demanding precise monitoring during use.	1500–3000
Severe – water suitable for salt-tolerant crops in well-drained soils under controlled use	3000–7500

According to Table 5.Water with high conductivity levels can harm root systems and growth media, leading to nutrient imbalances and problems with water absorption. Generally, the conductivity of clean water ranges from 0 to 0.6 mhos/cm [27]. The presence of salts in quantities represents as one of the reasons for the electrical conductivity of water, which makes the water a good conductor. Salts are evidence of the presence of ions with positive and negative charges in the water, and this is what was confirmed by McCleskey *et al.*, and Zahoor & Mushtaq [28, 29].

Total dissolved substances (TDS)

When analysing the results for TDS, it was observed that the lowest recorded value was 20 mg/L, while the highest reached 483 mg/L.A statistical analysis found that p- value=0.0189, which indicates a significant difference in TDS values between Al-Karkh and Rusafa districts, as shown in Table 6.

Table 6: Effect of station and condensate (AC) water on TDS mg/L

Stations	Al-Karkh district air conditioner water	Rusafa district air conditioner water	p-value
St: 1	230	39	$p<0.05$
St: 2	292	22	$p<0.05$
St: 3	325	32	$p<0.05$
St: 4	40	140	$p<0.05$
St: 5	290	111	$p<0.05$
St: 6	483	20	$p<0.05$
Mean ±SD	276.66±143.88	60.66±51.51	$P= 0.0189$

When comparing the results with the specifications of the Food and Agriculture Organization 2013, as shown in Table 7 [29], notice that the water is non-saline water, the total dissolved impurities TDS occurrence in water is considered as one of the reasons for the high water salinity, which affects plants in one way or another. These results are consistent with the findings of researchers regarding the increase in salinity due to total dissolved solids [28].

Table 7: Irrigation water quality according to TDS mg/L.

S.No	TDS mg/litre	Total salinity
1.	< 500	Non-saline water
2.	500–30 000	Saline water
3.	500–2 000	Slightly saline
4.	2 000–4 000	Medium saline
5.	> 4 000	Highly saline
6.	> 9 000	Very saline
7.	> 30 000	Brine

To avoid clogging problems, TDS levels should be less than approximately 640 mg/L. However, other problems affecting plant growth can be avoided when values are below 960 mg/L. These classifications are based on the conductivity levels mentioned above. Plant growth is significantly affected when TDS concentrations exceed 2000 mg/L. High TDS waters require extensive treatment or dilution, just like conductivity difficulties, to make the water suitable for irrigation [30].

Chloride (Cl^- in mg/l)

In another classification based on chloride (Cl^-) mg/L levels and its effect on crops, according to Bauder and his group [26], the results fell between 0.01 and 0.06 mg/L. When compare chloride concentrations between Al-Karkh and Rusafa districts, significant differences were found (p-value = 0.00003), as demonstrated in Table 8.

Table 8: Effect of station and condensate (AC) water on chloride (Cl^-) mg/L and their statistical analyse

Station	Al-Karkh district	Rusafa district	p-value
St: 1	0.05	0.01	$p<0.05$
St: 2	0.06	0.02	$p<0.05$
St: 3	0.06	0.02	$p<0.05$
St: 4	0.04	0.02	$p<0.05$
St: 5	0.05	0.01	$p<0.05$
St: 6	0.06	0.01	$p<0.05$
Mean ±SD	0.05± 0.00	0.01± 0.00	P= 0.00003

This means that it is generally safe for all plants, while plants classified as sensitive typically exhibit minor to moderate damage (Table 9).

Table 9: Irrigation water chloride (Cl^-) values and their plants response

Cl^- concentration	plants response
< 70	Usually shows no adverse effects and is safe for a wide range of plants
70–140	Sensitive plants respond with damage ranging from minor to moderate minor.
141–350	Damage to moderately tolerant plants ranges from minor to severe.
> 350	Severe damage to plants occurs.

The majority of crops can withstand up to 100 mg/L of chloride, while certain delicate plants may have issues with as little as 30 mg/L. Since chloride is difficult to remove from water, complex treatment methods such as distillation or reverse osmosis membranes are required. It is also acceptable to use low-chloride water for dilution [31].

Total hardness (TH)

The results of (TH) as CaCO3 showed that values ranged from 30 mg/L to 70 mg/L. A statistically significant differences (p-value = 0.61366) in TH values was found between Al-Karkh and Rusafa districts (Table 10).

Table 10: Effect of station and condensate (AC) water on TH mg/L and their statistical analyse

Station	Al-Karkh district	Rusafa district	p-value
St: 1	40	50	p<0.05
St: 2	40	50	p<0.05
St: 3	60	50	p<0.05
St: 4	30	60	p<0.05
St: 5	40	50	p<0.05
St: 6	70	50	p<0.05
Mean ±SD	46.66± 15.05	51.66± 4.08	P= 0.61366

When compared to Todd's specifications, the irrigation water quality is classified as Soft [32] as displayed in Table 11.

Table 11: Irrigation water quality classification according to TH as CaCO3.

S.No	Classification	Limiting value
1.	Soft	<75
2.	Moderately hard	75-150
3.	Hard	150-300
4.	Very hard	>300

Hardness concentrations above 150 mg/L will cause damage to water heaters, clog irrigation lines and pipelines, and accumulate on contact surfaces. Scale foliar deposits may also result from these levels. A water softener is only required to remove hardness if the hardness of the water is becoming problematic. Fertilization with calcium and magnesium, as explained below, may be necessary for exceptionally low hardness water with less than 50 mg/L [33].

Sodium (Na^+ in mg/l)

The results of this research showed that the lowest value for sodium (Na) was 0.9 mg/L and the level with the highest value was 37.8 mg/L. When comparing sodium concentrations between Al-Karkh and Rusafa districts, significant differences were found, with a p-value of 0.00012 (Table 12).

Table 12: Effect of station and condensate (AC) water on sodium (Na) mg/L and their statistical analysis

Station	Al-Karkh district air conditioner water	Rusafa district air conditioner water	p-value
St: 1	26.7	1.0	p<0.05
St: 2	27.8	1.0	p<0.05
St: 3	32.2	0.9	p<0.05
St: 4	19.0	1.0	p<0.05
St: 5	20.0	3.4	p<0.05
St: 6	37.8	4.5	p<0.05
Mean ±SD	27.25± 7.16	1.96± 1.57	P= 0.00012

When comparing it to the specifications of Shyamala and his group, as demonstrated in Table 13 [34], the water is classified as good for irrigation

Table 13: Adoption of sodium (Na) mg/L levels for the classification of water used in irrigation

Station	Category	The specified value
1	Excellent	<20
2	Good	20-40
3	Permissible	40-60
4	Doubtful	60-80
5	Unsuitable	>80

In recirculating irrigation systems, a concentration of sodium exceeding 50 mg/L was found to cause toxicity, especially in plants classified as sensitive [35].

Calcium (Ca^{+2} in mg/l)

The results of calcium (Ca^{+2}) mg/L measurement show that the highest value was 36 mg/L. Statistical analysis showed that sodium concentrations between Al-Karkh and Rusafa districts were significant with a p value of 0.00016 (Table 14). The presence of calcium with a range of 40–120, in irrigation water makes it more desirable due to its benefits to the plant [36].

Table 14: Effect of station and condensate (AC) water on calcium (Ca^{+2}) mg/L and their statistical analysis.

Station	Al-Karkh district	Rusafa district	p-value
St: 1	20	0.9	$p<0.05$
St: 2	21	1.2	$p<0.05$
St: 3	24	1.0	$p<0.05$
St: 4	18.0	1.5	$p<0.05$
St: 5	19.0	1.2	$p<0.05$
St: 6	36	3.5	$p<0.05$
Mean ±SD	23± 6.69	1.55±0.97	P= 0.00016

There may be a difference in the presence of calcium concentrations in plants. If its concentrations are low (less than 40 mg/L), calcium fertilization is used to compensate for the deficiency. However, increasing calcium to more than 100 mg/L causes adverse reactions, leading to a deficiency in phosphorus and/or magnesium. [37].

Magnesium (Mg in mg/l)

The results of the Mg++ measurement show that the highest value recorded was 24 mg/L. When the magnesium data were analysed on both the Al-Karkh and Rusafa sides, it was noted that the differences between the two districts were significant, with a p-value of 0.01970 (Table 15). In natural waters, Mg^{++} is generally present. Magnesium concentrations have a critical impact on identifying the relationship to total salinity and assessing the damage caused by sodium. A magnesium concentration of 6-24 mg/L is required [36].

Table 15: Effect of station and condensate (AC) water on Mg^{++} mg/L and their statistical analysis

Station	Al-Karkh district air conditioner water mg/L	Rusafa district air conditioner water mg/L	p-value
St: 1	5.2	0.3	$p<0.05$
St: 2	5.0	0.5	$p<0.05$
St: 3	6.5	0.4	$p<0.05$
St: 4	8.5	0.7	$p<0.05$
St: 5	10	0.7	$p<0.05$
St: 6	24	2.0	$p<0.05$
Mean ±SD	9.86± 7.18	0.76±0.62	P= 0.01970

Similar to calcium, magnesium in water usually comes from the rock and only becomes an issue when the concentration falls below 25 mg/L, at which point fertilizer containing magnesium must be added [38].Hard water contains a high concentration of minerals, especially calcium and magnesium. These minerals interfere with nutrient absorption, alter soil pH, impair root health, and lead to mineral accumulation in the soil [39]. The danger of sodium and magnesium is the accumulation of salt on the soil surface, which makes it difficult for water to seep into the plant roots [40].

Heavy metals

Lead (Pb)

The results of the examination showed the lead (Pb) levels to be the lowest at 0.003 mg/L and the highest at 0.056 mg/L. Statistically, it was found that lead concentrations in Al- Karkh and Rusafa districts showed significant differences, with a p-value of 0.00004 (Table 16). When these results are compared to the Iraqi standard of 1 mg/L, the values of the water tested in this research are within acceptable limits. According to the Iraqi Standard Specification, permissible limits and standards are adopted for evaluating water suitable for irrigation [19].

Table 16: Effect of station and condensate (AC) water on Pb and their statistical analysis

Station	Al-Karkh district	Rusafa district	p-value
St: 1	0.035	0.005	p<0.05
St: 2	0.040	0.006	p<0.05
St: 3	0.050	0.003	p<0.05
St: 4	0.030	0.004	p<0.05
St: 5	0.035	0.003	p<0.05
St: 6	0.056	0.004	p<0.05
Mean ±SD	0.041± 0.01	0.004± 0.001	P= 0.00004

Iron (Fe)

Cooling water tests in this research also showed that the lowest value of iron (Fe) was 0.07 mg/L, while the highest value was 2.8 mg/L. Statistical analysis of the data related to iron concentrations revealed significant differences , with a p-value of 0.00024 (Table 17). When compared to the Iraqi standard of 5 mg/L, it is within the permissible limits [19].

Table 17: Effect of station and condensate (AC) water on Fe and their statistical analysis

Station	Al-Karkh district air conditioner water	Rusafa district air conditioner water	p-value
St: 1	2.2	0.1	p<0.05
St: 2	1.8	0.78	p<0.05
St: 3	2.3	0.07	p<0.05
St: 4	1.6	0.75	p<0.05
St: 5	2.0	0.6	p<0.05
St: 6	2.8	0.1	p<0.05
Mean ±SD	2.11± 0.42	0.4± 0.34	P= 0.00024

Iron can be a complex issue with water quality that impairs plant growth and clogs irrigation systems. Iron levels in micro-irrigation systems must be less than 0.3 mg/L to avoid clogging. In overhead irrigation systems, foliar spotting may occur at levels exceeding 1.0

mg/L. In sensitive species, extremely high iron levels exceeding 5.0 mg/L may result in severe discoloration and plant poisoning. The most common places for iron toxicity issues to arise are in growth media that are acidic (pH less than 6.0). If the pH is higher than 7.0 to 7.5, sensitive species may also have induced iron deficiency [22].

The presence of heavy metals in air conditioner water may be due to air pollution from factory waste, car exhaust, and electric power generators [38].It has been observed that old and unclean cooling pipes corrode over time, leading to the formation of high concentrations of minerals and impurities such as iron and copper, in the condensate water [22].

Conclusion: This study concludes that condensate water from air-conditioning systems, normally lost as waste, can be considered a potential alternative water resource for irrigation. However, its main limitation is the lack of essential nutrients and minerals required for healthy plant growth. Although the detected heavy metals were within acceptable limits, they may gradually affect soil quality, particularly in confined settings such as containers. When combined with rainwater, condensate water may help maintain plant growth and balance mineral content more effectively.

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Conflict of Interest

The authors reported no potential conflicts of interest.

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