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Estimation of annual evaporation losses for the Makhoul Dam reservoir (under construction)

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ABSTRACT

The problem of evaporation is considered one of the most important problems that dam reservoirs suffer from due to economic losses and treatment costs. Makhoul Dam, a dam under construction in Iraq. In this research, a study was conducted to estimate the evaporation loss from the dam reservoir. A type A pan was used to measure daily evaporation for a full year starting from July 2022 until June 2023, and GiS software was used to estimate the shape of the reservoir based on the information available for the dam and DEM satellite images of the area. Two sites were chosen to measure evaporation, one in the city of Al-Zab, and the other in the village of Tal Ali, about 30 km from the dam. The results showed that the cumulative total annual evaporation from the Al-Zab and Tal Ali measuring stations amounted to 1547 mm/year and 1766 mm/year, respectively. The evaporation rate from the two stations reached 1656 mm/year. Two assumptions were made for the method of evaporation from the reservoir. The first assumed that the reservoir was full throughout the year. In this case, the evaporation loss from the tank is 380,631,600 cubic meters/year, or the equivalent of 15% of the stock volume. The second hypothesis assumed that the inventory varies throughout the year, starting with the highest level in the spring and then decreasing. Gradually until the end of autumn, then it increases again in winter. In this hypothesis, the annual losses will be 288,175,555 cubic meters/year, equivalent to 11% of the stock volume.

Introduction

Water resources are among the most important requirements for the continuation and perpetuation of human life, and life cannot continue Without water, it is the resource that has a major role in all aspects of life and is the main pillar of development. The establishment of hydraulic facilities such as dams and reservoirs for the purpose of storing surplus water during the season Flood is one of the most important practices for the development and management of water resources, flood prevention and control [1]. A dam can be defined as an obstacle or barrier built across a stream or river. there is many uses for dams such as navigation, irrigation, electricity, flood control, etc. Archaeological evidence helps estimate that the first man-made dam is at least 3,000-5,000 years old. Whenever it was built, this first dam was a semi-irrigation dam [2]. There are more than 45,000 large dams built around the world for various purposes such as power generation, flood control, domestic or industrial water supply [3]. There are many problems that accompany dam construction, some of which reduce its value or may render it useless. The loss of water from reservoirs is a great challenge in water-scarce and arid areas, in particular, the evaporation losses. In dry areas, Reservoirs can be considered one of the greatest freshwater consumers because they lose too much water by evaporation in water-scarce regions, leading to a lack of water resources Evaporation is the major loss from the system but, contrary to losses by infiltration, the evaporative loss does not have any direct benefits to the environment of the reservoir [4]. More than one billion people living in arid regions are expected to face water scarcity by 2025, forcing reductions in per capita water use across multiple sectors, including food production. Worldwide, but especially in arid regions, the effects of climate change and rising temperatures threaten to reduce available surface water through enhanced evaporation, especially in surface storage reservoirs. Recently, reservoirs across the southwestern United States have been experiencing extremely low water levels, with water demands increasing and supplies the effective capacity of water stored by the mountain snowpack has been reduced by recent intense droughts, as well as from earlier snowmelt and runoff as a result of rising temperatures, rain-on-snow events, and enhanced dust on snow [5]. reservoirs evaporate more rapidly than did the natural surface water flow before the dam was built because dams generally increase the surface area of the body of water. Thus, more of the water surface is exposed to air and direct sunlight, increasing evaporation. This “lost” water is referred to as having been consumed because it is removed from the system. In some cases, this water consumption can be quite substantial. The present trend of global warming speeds up the shrinkage of the water area relative to the land area. This is especially true for lakes and reservoirs, and the environment around them undergoes changes that have degraded the lives of the inhabitants and impacted their economic activities. Many of the world’s lakes and reservoirs are facing the threat of shrinkage [6]. [5] conducted a study of the evaporation problem for the western part of the United States of America, and the study concluded that reservoir evaporation is an inconsistent and imprecise component of the water cycle within the water resource infrastructure in the arid and semi-arid western United States. Researcher [7] conducted an analytical study to reduce evaporation in Qattina Lake in Syria. The researcher proposed two solutions based on the construction of two dams separating the shallow parts from the deep parts, and the researcher conducted an evaporation assessment for both parts. [8] conducted a detailed daily evapotranspiration study on the Alavian Dam reservoir, located in northwest Iran. The researchers used modeling to obtain the daily water temperature distribution of the reservoir and calibrated and validated the water temperature model using a three-year observation period. Dataset (2013-2016). The researchers determined evaporation rates using 30 experimental methods. These methods were evaluated and categorized with respect to BREB values. [9] conducted a detailed study of the evaporation dilution efficiencies of five $Water products (monolayer), E-VapCap (floating cap), NetPro shade cloth (suspended cap), Raftex (standard cap), and polyacrylamide (chemical) on research tanks. Located at the University of Southern Queensland (USQ), Toowoomba. [10] conducted research aimed at developing an experimental model to estimate evaporation from reservoirs located in dams in arid and semi-arid regions. [11] conducted a study aimed at determining the most appropriate evapotranspiration methods Dosti Dam reservoir in Iran. [6] studied evaporation estimation for the Haditha Dam reservoir. The researchers used meteorological data and international equations for evapotranspiration. [12], conducted a feasibility study of different evapotranspiration estimation methods to find an optimal method with a fair trade-off between cost and accuracy.

1. Study area of Makhoul Dam (under construction)

Makhoul Dam is one of the dams proposed to be built on the Tigris River Basin in Iraq, Makhoul dam is located in the northeastern part of Salah al-Din Governorate and the western part of Kirkuk Governorate on the administrative borders of Baiji district, Hawija district, and Shirqat district, The dam is located 200 km north of the Samarra Dam on the Tigris River, after the confluence of the Tigris River with two important tributaries, the Upper Zab and the Lower Zab. Therefore, the construction of the dam project will lead to controlling the flood waters of the river and its tributaries. It is one of the most important large hydraulic projects proposed by the international standards of the International Association of Large Dams. Work on the dam began in 2001, and construction operations stopped in 2003 for financial and security reasons. Work on building the dam was resumed in 2021 by the Ministry of Public Works. Water resources are still under construction, [1]. Table 1 showing the design specifications of Makhoul Dam, also Figure 1 represents the location of the Makhoul reservoir and dam on the map of Iraq.

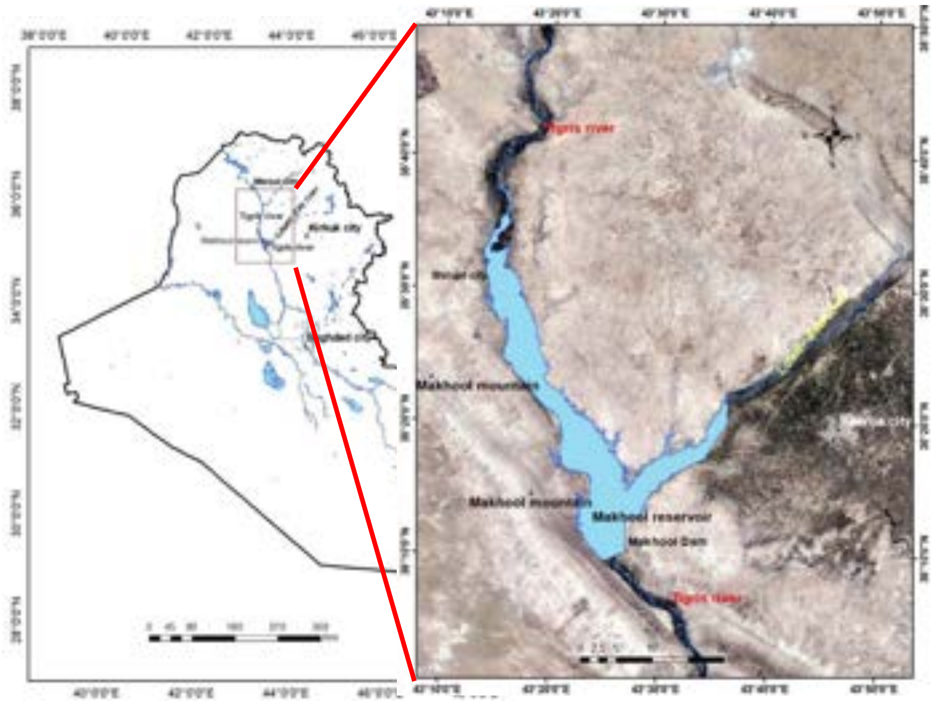

Figure 1. The location of the Makhoul dam on the map of Iraq [The work of the researcher]

Table 1. Showing the design specifications of Makhoul Dam [1]

1	Dam top level	160 m above sea level
2	The highest height of the dam is at the lowest point at the bottom of the river	56 m
3	width of the dam crest	12 m
4	The length of the dam at the top level	3670 m
5	The highest possible flood level	152.15 m
6	The highest annual operating level	150 m
7	The lowest annual operating level	140 m

2. Estimate Dam Reservoir

GIS, surfer and Excel programs were used for the purpose of geometric analysis of the reservoir and to calculate the shape, size and area of the dam reservoir based on the given data of the height of the dam. Then, the total annual load of sediment entering the Makhoul Dam reservoir was estimated, the efficiency of the trap was estimated. and comparison between the results obtained from the experimental work and the equations. DEM visualizations with a resolution of 30 meters were used to estimate the shape of the lake using GIS programs (ArcGIS and Global Mapper programs), then the surfer program was used to calculate the size and shape of the reservoir at each level, which begins with the lowest operating level (140 meters above sea level) and the highest operating level is (150 meters above sea level), as mentioned previously in Table 1. The shape of the reservoir was drawn, Figure 2 represent the Makhoul Dam reservoir at highest operating level. The reservoir volume and area at each level were calculated using a server program, as shown in Table 2. The area of the Makhoul Dam reservoir at the highest operating level (150 meters above sea level) is 229.85 square kilometers, and the total volume of the reservoir is 2.54 billion cubic meters. The reservoir extends in two branches, one of which extends into the Tigris River basin and extends for a distance of 50 km, and the second branch extends into the lower Zab River basin and extends a distance of about 25 km from the center of the dam.

Figure 2. Makhoul reservoir at maximum operating level

Table 2 Total volume and surface area of Makhoul Reservoir

level(m)	surface area(km2)	Total storage volume ($m3*10^6$)
140	112.24	850.95
141	124.47	980.33
142	134.90	1095.02
143	143.68	1235.72
144	152.21	1390.51
145	162.15	1553.05
146	173.29	1726.60
147	187.38	1908.38
148	203.42	2111.46
149	215.35	2325.47
150	229.85	2541.38

3. The theoretical part

A number of empirical equations are available for the estimation of evaporation. Some commonly used expressions include the following:

*Dalton's law:

E=C(ew-ea) …………….(1)

Where: E: rate of evaporation (mm/day),

C: constant,

ew: saturation vapor pressure (mm Hg),

ea : actual vapor pressure (mm Hg).

Many researchers have developed equations to predict daily and annual evaporation, and we will briefly mention some of them: Meyer's Formula, Fitzgerald's Formula, Rower's Formula, Penman Method, Priestley–Taylor Method, De Bruin Method, and Linacre Equation [6], [13], [14]. To calculate evaporation in this research four equations experimental equations were used from the equations. and their results were compared with the measurements of the type A fryer used in the study.

1. **Meyer's Formula:**

$E_M=K_m\,(e_w-e_a)\,(1+U_a16)$ ….........(2)

$K_m=0.36$

2. **Fitzgerald's Formula:**

$E_F=(0.4+1.24u_o)\,(e_w-e_a)$ …......…(3)

3. **Rower's Formula:**

$E_R=0.771(1.465-0.000732p_a)$

$(0.44+0.0733u_o)\,(e_w-e_a)$ …......…(4)

4. **Linacre Equation**

$$E_L=\frac{700*\frac{(T+0.006h)}{100-A}+15(T-T_a)}{80-T} \quad \text{…..............(5)}$$

$$T_d=\frac{b\left[\ln\left(\frac{R_H}{100}\right)+\frac{(a*T)}{(b+T)}\right]}{a-\ln\left(\frac{R_H}{100}\right)-\frac{a*T}{(b+T)}} \quad \text{…………..(6)}$$

Tables 5 and 6 represent the monthly values and the daily rate of evaporation according to the four equations above, in addition to the monthly evaporation value for the A-type pan for the two sites, Al-Zab and Tal Ali, respectively.

3. Field and laboratory work

Evaporation was calculated in two ways. The first was by using a Type A evaporation vessel to estimate daily evaporation for a full year starting from July 2022 until June 2023. The evaporation vessel was manufactured according to the specifications of this device Figure 3 [13], and it was made of galvanized iron with a wooden stand. Air movement is allowed according to the specifications as shown in Figure 4. The dimensions of the fryer are 1220 mm in diameter and 255 mm in diameter Depth. The pan is made of galvanized iron sheets and coated with a rust-preventing paint. The fixed-point scale indicates the water level. The cylindrical scale shown in the figure is used to add or remove water while keeping the water level in the pan to a constant mark. The top of the pan is covered with galvanized iron wire mesh to protect the water in the pan from birds. Moreover, the presence of a wire mesh makes the water temperature more uniform during day and night.

Two locations were chosen for the pan to measure evaporation, one in the Al-Zab district and the other in the village of Tal Ali, as shown in the map Figure 5.

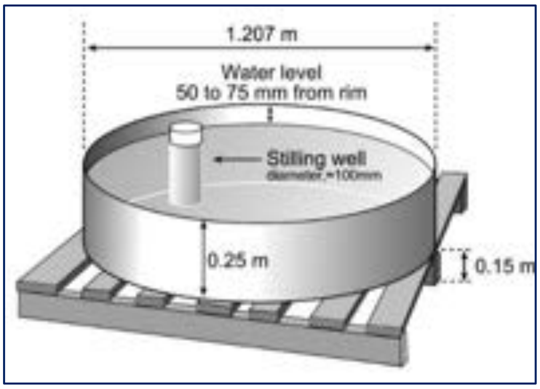

Figure 3. Specifications of evaporator pan type A

Daily measurements were taken every 24 hours and these measurements included:

1. The amount of subsidence of the water surface in the pan (mm).
2. Rainfall amount (mm).
3. Calculate the net daily evaporation (E_p) of the pan after removing the increase due to the amount of rainfall.
4. Calculating the correct daily evaporation (E) is done by multiplying the daily evaporation of the frying pan by the evaporation correction factor (C_p) and its value equals 0.6 - 0.8, where the average is taken as 0.7 [13].

$E=E_p*C_p$ ……………..(7)

5. Minimum and maximum Celsius temperatures.
6. Average wind speed (km/h).
7. Humidity percentage.
8. Length of day (hours).
9. Atmospheric pressure (kPa).

Figure. 5 Location of evaporation measurement station

Figure 4 A picture of a type A pan used to measure evaporation in the research

Tables 3 and 4 show the monthly rates of evaporation for 12 months and for the two measuring stations, Al-Zab and Tal Ali.

Tables 3. The monthly rates of evaporation from AL-Zab stations

months		Rain (mm)	E (mm)	temp. (C^o)	Wind (km/hr)	Rel. Humidity %	Atmos. Pressure (kPa)
July	Daily rate	0	9.269	37.112	15.677	12.83	99.79
	sum	0	287.35				
August	Daily rate	0	8.309	38.241	18.096	18.806	100.07
	sum	0	257.6				
Sept.	Daily rate	0	6.206	31.435	12.903	18.333	100.56
	sum	0	186.2				
Octo.	Daily rate	0.032	3.364	26.387	11.709	29.129	101.41
	sum	1	104.3				
Nov.	Daily rate	1.233	1.493	16.709	8.741	59.4	101.83
	sum	0	44.8				
Dec.	Daily rate	0.951	0.801	12.548	9.419	83.645	102.06
	sum	0	24.85				
Jan.	Daily rate	0.612	0.767	9.693	10.645	69.677	102
	sum	0	23.8				
Feb.	Daily rate	0.178	1.6	10.696	11	47	102
	sum	5	44.8				
March	Daily rate	1.935	2.82	18.112	14.419	49.290	101.58
	sum	0	87.5				
April	Daily rate	0.8	2.87	21.290	12.161	33.6	101.23
	sum	0	86.1				
May	Daily rate	0	5.554	28.435	14.129	25.161	101.12
	sum	0	172.2				
June	Daily rate	0.133	7.583	33.112	14.87	17.8	100.5
	sum	0	227.5				

Tables 4. The monthly rates of evaporation from Tal Ali stations

months		Rain (mm)	E (mm)	average temp.	Wind km/hr.	relative humidity %	Atmos. Pressure (kPa)
July	Daily rate	0	10.409	37.209	16.677	11.838	99.79
	sum	0	322.7				

Aug.	Daily rate	0	9.370	38.129	17.935	13.741	100.077
	sum	0	290.5				
Sept.	Daily rate	0	6.183	33.403	12.129	13.8	100.566
	sum	0	185.5				
Octo.	Daily rate	0.032	4.2	28.790	11.967	19.193	101.419
	sum	1	130.2				
Nov.	Daily rate	1.113	1.666	19.403	10.419	38.566	101.833
	sum	33.4	49.98				
Dec.	Daily rate	0.783	0.945	14.516	7.709	54.8	102.033
	sum	23.5	28.35				
Jan.	Daily rate	1.322	0.959	11.338	10.645	58.741	102
	sum	41	29.75				
Feb.	Daily rate	0.178	1.7	11.089	11	47	102
	sum	5	47.6				
March	Daily rate	2.096	2.8	18.177	14.419	49.290	101.580
	sum	65	86.8				
April	Daily rate	0.866	4.036	21.290	12.161	33.6	101.233
	sum	26	121.1				
May	Daily rate	0.129	6.570	28.435	14.129	25.161	101.129
	sum	4	203.7				
June	Daily rate	0.133	9.006	33.112	14.870	17.8	100.5
	sum	4	270.2				

Table 5 Monthly values and the daily rate of evaporation according to the four equations for Al-Zab station

months		E(mm)	E_M(mm)	E_F(mm)	E_R(mm)	E_L(mm)
July	Daily rate	9.269355	29.57695	822.642	70.74633	21.50952
	sum	287.35	916.8854	25501.9	2193.136	666.7951
August	Daily rate	8.309677	31.08856	908.8486	76.1373	20.60036
	sum	257.6	963.7455	28174.31	2360.256	638.6111
September	Daily rate	6.206667	19.82243	495.7509	45.14753	16.76041
	sum	186.2	594.6729	14872.53	1354.426	502.8123
October	Daily rate	3.364516	12.01045	285.8123	26.75568	11.69046
	sum	104.3	372.3239	8860.18	829.4261	362.4042
November	Daily rate	1.493333	3.484726	70.39411	7.254255	5.234969
	sum	44.8	104.5418	2111.823	217.6276	157.0491

December	Daily rate	0.801613	1.022378	21.63672	2.167806	2.778954
	sum	24.85	31.69371	670.7384	67.20199	86.14757
January	Daily rate	0.767742	1.643282	37.27704	3.58546	2.838243
	sum	23.8	50.94175	1155.588	111.1493	87.98554
February	Daily rate	1.6	3.219471	73.38163	7.038653	4.277193
	sum	44.8	90.14518	2054.686	197.0823	119.7614
March	Daily rate	3.070968	5.705622	155.3882	13.5005	6.1614
	sum	95.2	176.8743	4817.033	418.5156	191.0034
April	Daily rate	2.87	19.44077	474.7171	43.79865	9.004302
	sum	86.1	583.223	14241.51	1313.959	270.1291
May	Daily rate	5.554839	14.83035	390.7192	34.56849	13.06064
	sum	172.2	459.7408	12112.29	1071.623	404.88
June	Daily rate	7.583333	23.53473	648.9448	56.04582	17.60206
	sum	227.5	706.0419	19468.34	1681.375	528.0617

Table 6 Monthly values and the daily rate of evaporation according to the four equations for Tal Ali station

months		E(mm)	E_M(mm)	E_F(mm)	E_R(mm)	E_L(mm)
July	Daily rate	10.40968	31.30698	905.5703	76.29233	22.07598
	sum	322.7	970.5165	28072.68	2365.062	684.3555
August	Daily rate	9.370968	32.87247	967.5288	80.77083	22.15368
	sum	290.5	1019.047	29993.39	2503.896	686.7639
September	Daily rate	6.183333	22.96115	562.9135	51.83857	19.48415
	sum	185.5	688.8345	16887.41	1555.157	584.5245
October	Daily rate	4.2	15.3152	362.8054	34.04986	14.34297
	sum	130.2	474.7713	11246.97	1055.546	444.632
November	Daily rate	1.666	6.540378	142.575	14.03826	7.77137
	sum	49.98	196.2114	4277.249	421.1477	233.1411
December	Daily rate	1.016129	1.022378	21.63672	2.167806	2.778954
	sum	31.5	31.69371	670.7384	67.20199	86.14757
January	Daily rate	0.959677	2.609786	59.4775	5.70541	3.808175
	sum	29.75	80.90337	1843.803	176.8677	118.0534
February	Daily rate	1.7	3.283284	74.96098	7.183211	4.358048
	sum	47.6	91.93194	2098.907	201.1299	122.0254
March	Daily rate	2.8	5.853595	162.0976	13.95889	6.186016
	sum	86.8	181.4614	5025.027	432.7256	191.7665
April	Daily rate	4.036667	19.44077	474.7171	43.79865	9.004302
	sum	121.1	583.223	14241.51	1313.959	270.1291
May	Daily rate	6.570968	14.83035	390.7192	34.56849	13.06064
	sum	203.7	459.7408	12112.29	1071.623	404.88
June	Daily rate	9.006667	23.53473	648.9448	56.04582	17.60206
	sum	270.2	706.0419	19468.34	1681.375	528.0617

4. Results and Discussion

The four equations selected (2,3,4,5) were applied to the weather variables recorded for the two measurement sites (Al-Zab and Tal Ali) the results for the daily and monthly averages are shown in Tables 5 and 6. The monthly and daily variation of evaporation was plotted for the two study sites.

Figures 5 and 6 show the variation of the daily and cumulative evaporation rates, respectively, during the months of the year for the Al-Zab site, where it appears that the evaporation values estimated by the equations differ from the evaporation values measured by Pan A. It appears that the Lenacre equation was the closest in the estimation, but it is more than double the distance. About measuring rates with a pan. Then the Meyer equation comes in second place, where it estimated evaporation to be 3 times the evaporation measured by the frying pan. In third place was the Rower equation, where the estimate ranged from 4-7 times the evaporation rate measured by the frying pan. In last place comes the Fitzgerald equation, where the guess was significantly far from what was measured by the pan.

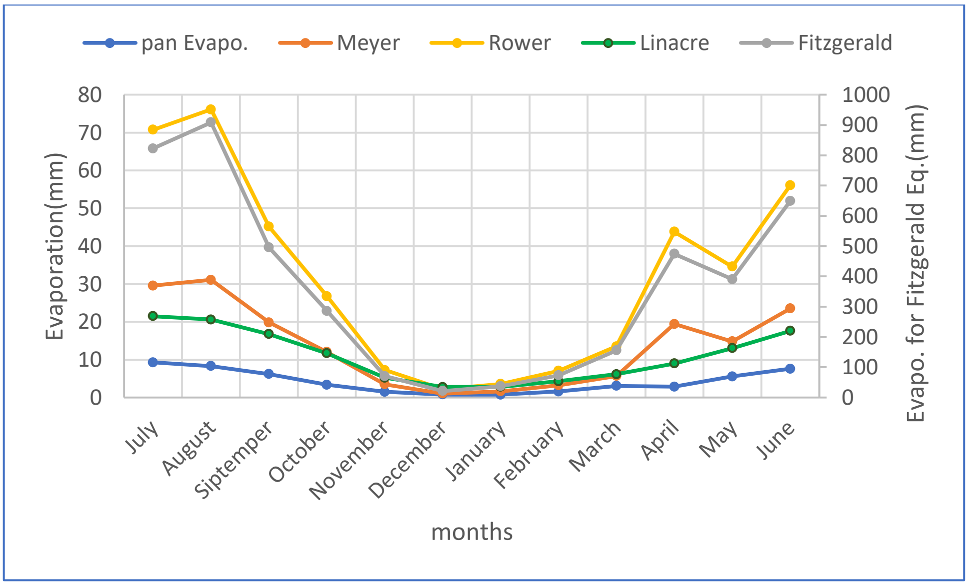

Figure 5. Average Daily equations evaporation for Al Zab station

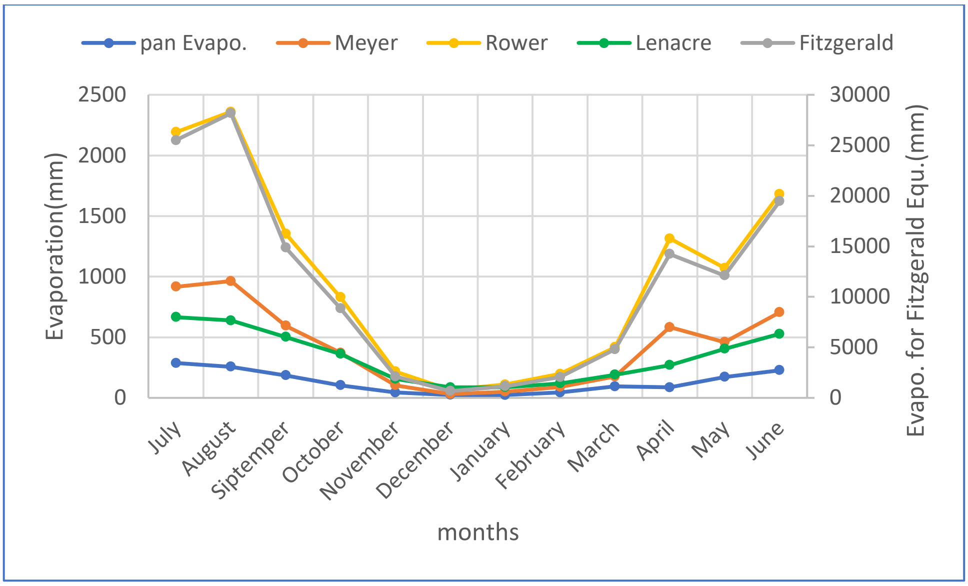

Figure 6. Cumulative evaporation by equations for Al Zab station

The situation was repeated at the Tal Ali site, as shown in Figures 7 and 8, where the four equations did not succeed in estimating evaporation, and the sequence of departures from the results measured with the frying pan was similar to the Al-Zab site, with some differences that had no effect, as the Lenacre equation remained closer in terms of estimating evaporation. However, it still gave results more than double the results of measuring with pan. Then the rest of the equations are in the same sequence as mentioned on the Zab site. From the above, we conclude that the four equations did not succeed in estimating evaporation in the study area, so the measurement will be adopted using Pan-A results to calculate the annual losses of evaporation from the dam reservoir.

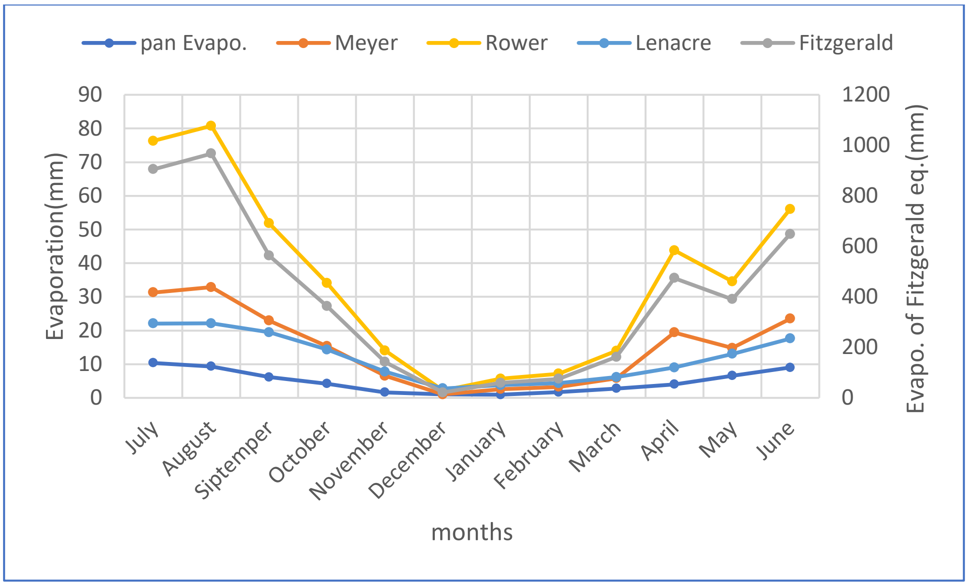

Figure 7. Average Daily equations evaporation for Tal Ali station

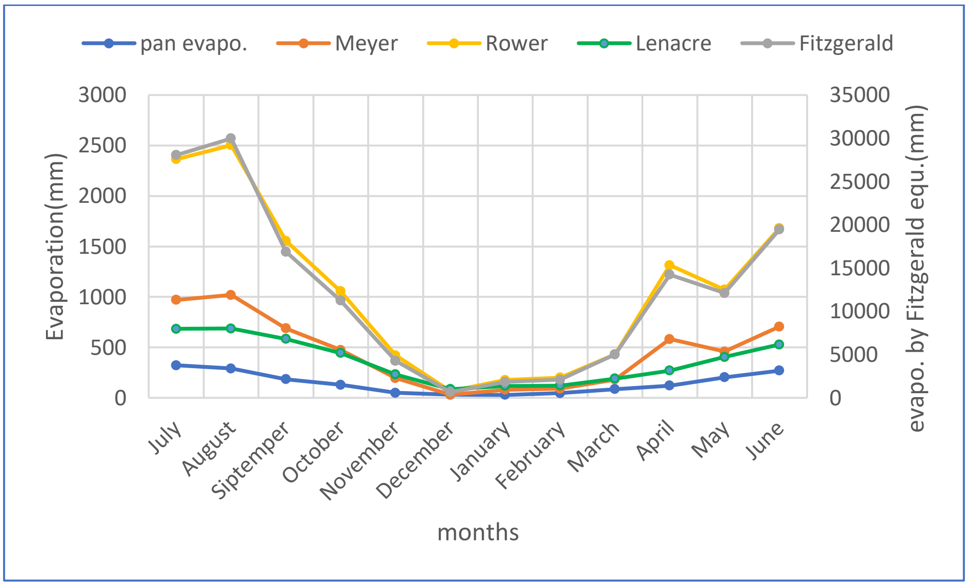

Figure 8. Cumulative evaporation by equations for Tal Ali station

from Figures 9 and 10, it becomes clear to us the type of variation in evaporation values during the study period, as the month of July recorded the highest daily evaporation value of 9.27 mm/day for the Al-Zab site and 10.41 mm/day for Tal Ali site. This was also recorded the month is the highest cumulative evaporation during the month for both the Al-Zab and Tal Ali measurement sites, where the cumulative evaporation at the Al-Zab site during the month of July reached 287.35 mm/month, and at the Tal Ali site the monthly evaporation in July reached 322.7 mm/month, and it is clear from the measurement record that the reasons leading to this are high temperatures to their maximum levels, wind speed as well, and low humidity. Relative to its lowest levels and atmospheric pressure as well. The two figures also show that the month of January recorded the lowest daily and cumulative evaporation rate during this period for the two sites as well, as the Al-Zab site recorded a daily evaporation rate of 0.767 mm/day, a cumulative evaporation rate during January of 23.8 mm/month, and the Tal Ali site recorded a daily evaporation rate of 0.959 mm/day the monthly evaporation rate reached 29.75 mm/month in January, due to temperatures reaching their lowest levels and calm wind speeds, in addition to relative humidity reaching its highest levels during the year, as well as atmospheric pressure. The results shown in the previously mentioned figures also showed that the evaporation rates recorded at the Tal Ali measuring station are higher than those at the Al-Zab measuring station and for all months. The reason may be that the location effect of the Al-Zab station has a role in this decrease, as the station is located in the city of Al-Zab at an altitude of about 160 meters above the level. Sea level, while Tal Ali station is located at an altitude of 180 meters above sea level, in addition to the influence of Mount Makhoul, which is located west of the city of Zab, and in turn affects the prevailing westerly winds in the region. The third reason is the city's location between the Zab and Tigris rivers, which increases the relative humidity even more. The annual cumulative total of evaporation using Pan A and measured at the Al-Zab site was 1547 mm/year, while the annual cumulative total of evaporation at the Tal Ali measurement site was 1766 mm/year, while the annual cumulative total of the annual evaporation rate at the two measurement sites will be taken and assumed as the annual evaporation rate for the dam's reservoirs. That is, the annual evaporation will be 1656 mm/year.

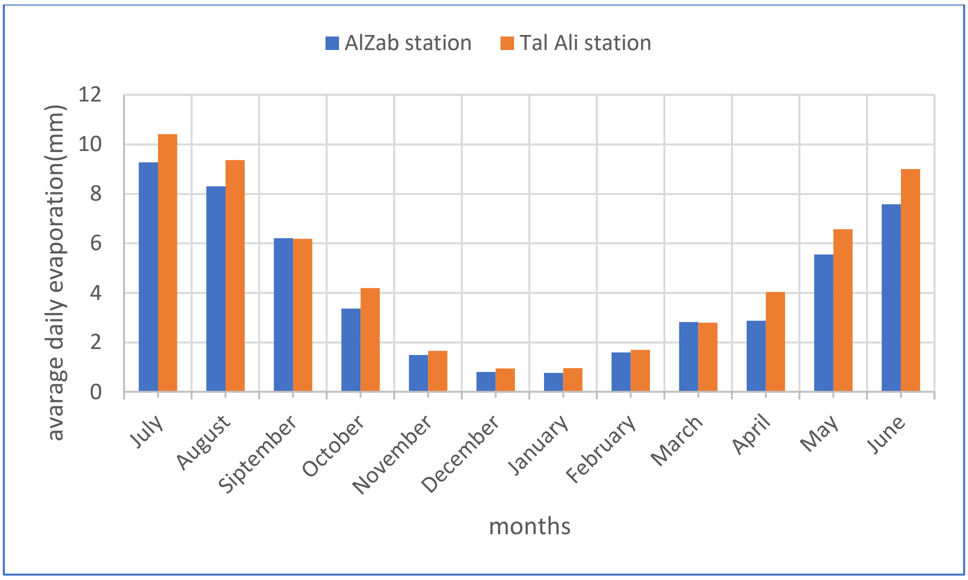

Figure 9. Average Daily pan evaporation for all months

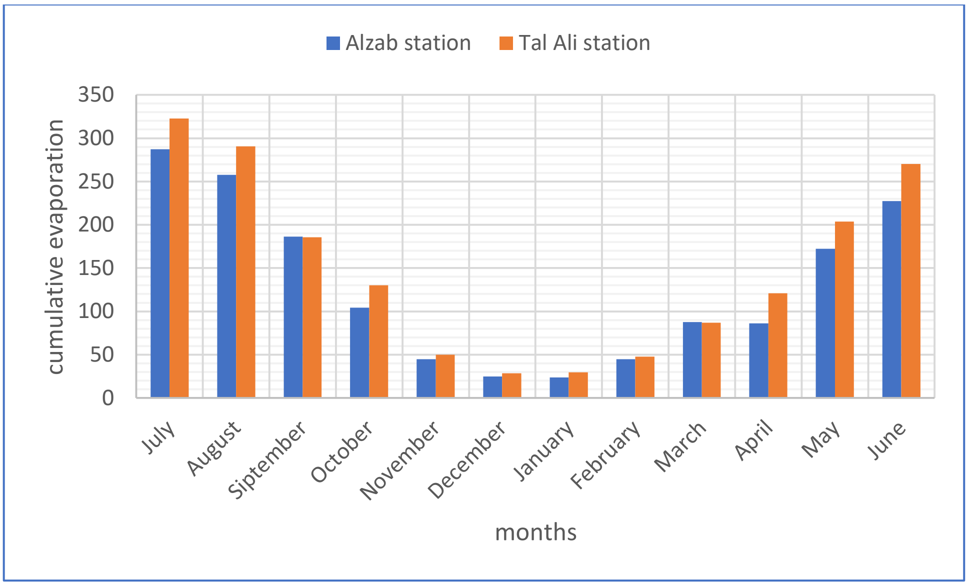

Figure 10. Cumulative pan evaporation for all months

Estimating the annual evaporation losses of the reservoir There are two hypotheses for the reservoir area.

A- The first is to consider the most dangerous case, which is that the reservoir is full all year round, and from Table 2, the highest level of the reservoir is 150 meters, and the total area of the reservoir in this case is 229.85 square kilometers. In this case, the annual evaporation losses from the Makhoul Dam reservoir will be 380,631,600 cubic meters/ year.

B- The second hypothesis suggests that Makhoul reservoir will be completely full at the end of spring and then begin to decline as a result of summer consumption until the end of autumn and begin to increase again as shown in table 7 and figure 11. In this hypothesis, the evaporation rate will be taken for each month for the two measurement sites. It will also be assumed that the decrease in the reservoir level is regular from May to August, then the decrease decreases from September to November by 1 meter per month, then it returns to rise from December to April by 2 meters per month. The total annual evaporation losses in this hypothesis amounted to 288,175,555 cubic meters, which is about 30% less than the estimate in Hypothesis A.

If the first hypothesis is adopted, the annual evaporation losses from an alcohol tank amount to 15% of the storage. If the second hypothesis is adopted, the total evaporation losses amount to about 11% of the storage.

Table 7. Evaporation losses from Makhoul reservoir according to hypothesis B

months	monthly evaporation rate(mm)	Reservoir level(m)	surface area(km^2)	Lost monthly evaporation (m3*10^6)
May	187.95	150	229.853036	43.20087812
June	248.85	148	203.426975	50.62280273
July	305.025	146	173.29138	52.85820318
August	274.05	144	152.215458	41.71464626
September	185.85	142	134.905632	25.07221171
October	117.25	141	124.471576	14.59429229
November	47.39	140	112.241166	5.319108857
December	26.6	141	124.471576	3.310943922
January	26.775	143	143.687553	3.847234232
February	46.2	145	162.157193	7.491662317
March	87.15	147	187.387231	16.33079718
April	103.6	150	229.853036	23.81277453
summation				288.1755553

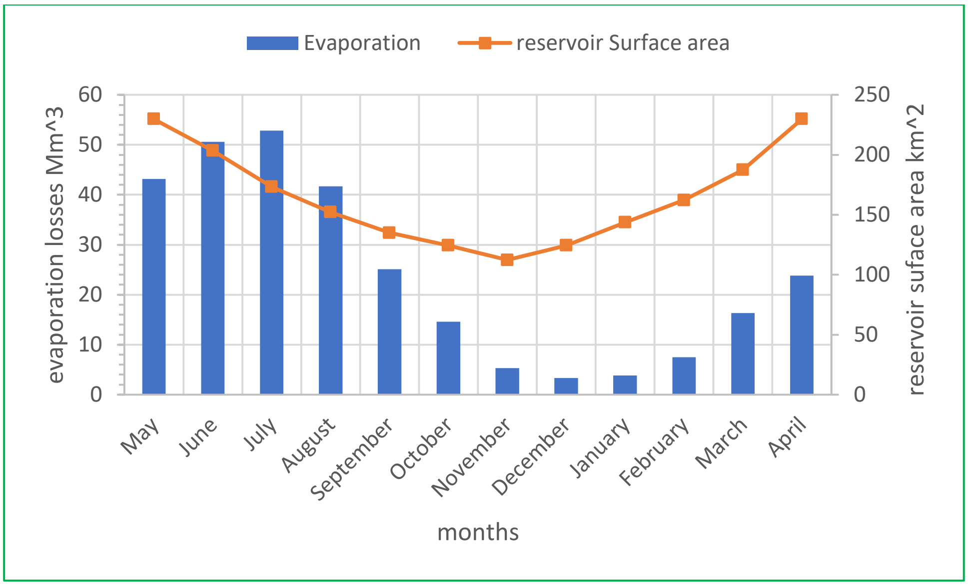

Figure 11. Evaporation losses from Makhoul reservoir according to hypothesis B

Conclusions

Evaporation was measured using Pan A at the Al-Zab and Tal Ali measurement sites. Daily measurements were taken for a whole year in which evaporation, maximum and minimum temperatures, amount of rain, wind speed, relative humidity, and atmospheric pressure were measured. Pan evaporation was compared with four results of four equations used by previous researchers, and the points were deduced. next:

1. The value of evaporation is directly proportional to the average temperature and wind speed and inversely proportional to relative humidity and atmospheric pressure.

2. The month of July recorded the highest daily evaporation value of 9.27 mm/day for the Al-Zab site and 10.41 mm/day for the Tal Ali site. This month also recorded the highest cumulative evaporation during the month for both the Al-Zab and Tal Ali measurement sites, where the cumulative evaporation for the Al-Zab site during the month reached July 287.35 mm/month, and at the Tal Ali site, monthly evaporation in July reached 322.7 mm/month.

3. the month of January recorded the lowest daily and cumulative evaporation rate during this period for the two sites as well, as the Al-Zab site recorded a daily evaporation rate of 0.767 mm/day, a cumulative evaporation rate during January of 23.8 mm/month, and the Tal Ali site recorded a daily evaporation rate of 0.767 mm/day. 0.959 mm/day the monthly evaporation rate reached 29.75 mm/month in January.

4. the evaporation rates recorded at the Tal Ali measuring station are higher than those at the Al-Zab measuring station and for all months.

5. The four equations did not succeed in estimating evaporation in both the Al-Zab and Tal Ali sites, and the sequence of deviations from the results measured with the pan varied between the four equations, where the Lenacre equation was closest in terms of estimating evaporation. However, it still gives more than twice the results of measuring with a pan. Then the rest of the equations gave a guess for evaporation that was very far from the pan results.

6. The annual cumulative total of evaporation using Pan A and measured at the Al-Zab site was 1547 mm/year, while the annual cumulative total of evaporation at the Tal Ali measurement site was 1766 mm/year, therefore the annual evaporation rate at the two measurement sites will be taken and assumed as the annual evaporation rate for the dam's reservoirs. That is, the annual evaporation will be 1656 mm/year.

7. If we assume the worst case for evaporation, which is that the dam's reservoir is full throughout the year, the area of the lake will be 229.85 square kilometers. In this case, the annual evaporation losses from the Makhool Dam will be 380,631,600 cubic meters, or about 15% of the volume of the reservoir.

8. If we assume that the size of the tank will change from its highest value in May and decline due to consumption until the lowest level in December, the losses due to evaporation will be 288,175,555 cubic meters, or about 10% of the amount of storage.

Recommendations

1. Since the problem of evaporation is a major problem and has a costly impact on water resources in Iraq, as our current study has proven, it is recommended to conduct a study of methods for mechanical covering of reservoirs and the possibility of integrating them with environmentally friendly options such as covering with solar panels and the economic feasibility of that.

2. Conducting a study of the economic feasibility of using chemical coating to reduce evaporation from the Makhool Dam reservoir, whether using existing materials or finding new materials for this purpose.

3. Study of a project concerned with addressing and reducing the problems of evaporation by using the vegetation cover of the area to reduce soil erosion and thus reduce sediments reaching the dam reservoir, as well as humidifying the atmosphere and reducing heat and thus reducing evaporation.

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