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Water Loss Through Evaporation from Some Egyptian Lakes and Nasser Reservoir

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ABSTRACT

The objective of this study was to estimate the amount of water loss from 6 Egyptian lakes and Naser reservoir and compare it with supplied water in Egypt. The total surface areas of the 6 lakes and Nasser reservoir were found to be 2254.2 km^2 and 6276 km^2, respectively; they are currently in operation. Total evaporative loss from water surfaces was 17.085 x 10^9 m^3 per year, of which 3.757 x 10^9 m^3 is from lakes and 13.328 x 10^9 m^3 from the Naser reservoir. This amount of water loss through evaporation is greater than the 9.6 x 10^9 m^3 of the groundwater, and it is greater than the amount of the re-use of agriculture drainage water (13.5 x 10^9 m^3/year), rainfall (1.3 x 10^9 m^3) and the destination of seawater (0.35 x 10^9 m^3).

INTRODUCTION

Studies on climate change conclude that global warming will cause systematic changes in the components of the hydrological cycle and hydrological systems, such as alterations in precipitation patterns, intensity and extremes, with a particular increase in evaporation that will affect the availability of water. At present, population growth and economic activities exert tremendous pressure on water resources **(Goudie, 2018; Molle & Closas, 2020)**; therefore, the country requires a new management orientation not only to increase water availability but also to reduce its losses.

Water sources in Egypt as mentioned in **MWRI Report (2017)** are the Nile River (55.5 billion m^3/year), groundwater (9.6 billion m^3/year), rainfall (1.3 billion m^3/year), destination of sea water (0.35 billion m^3/year) and re-use of agriculture drainage water (13.5 billion m^3/year). The Nile provides about 93% of the annual renewable water resources in Egypt, as the share of 55.5 billion cubic meters per year was allocated to Egypt according to the Nile Water Agreement in 1959.

Water Challenges in Egypt meeting the needs of many water users increases the stress of Egypt's relatively fixed water resources. The ongoing effects of climate change also include reduced rainfall, increased temperatures and even changes in the direction of the Nile's flow. It is noteworthy that, the country is dependent on the Nile River Which passes through eleven countries, and the journey of the Nile eventually ends when it spreads and empties into the Mediterranean, and this means that it is necessary not only to protect and clean the waters of the Nile for the sake of Egyptian water security, but also to protect the health of the Mediterranean ecosystem. In addition, agriculture uses about 85% of the available fresh water resources in Egypt, and irrigation water quality is a serious concern. Most agricultural land is heavily irrigated and polluted with industrial effluents and untreated sewage, which are usually dumped in open drains.

One of the most effective water loss processes is the evaporation from natural bodies, such as lakes or artificial water bodies including dams **(Gokbulak and Ozhan, 2006)**. Water loss through evaporation in lakes and reservoirs is a problem that can be of considerable economic importance, particularly in arid areas with minimal rainfall, and a challenge for water resource management. Due to this phenomenon, the losses can reach, under certain conditions of extreme solar radiation, up to 75% of the precipitated water.

Egypt has 15 lakes, these are; Lake Bardawil, Lake Burullus, Lake Idku, Lake Manzalah, Lake Maryut, Lake Nasser, Toshka lake, Lake Temsah, Mora Lakes, Lake Qarun, Wadi El-Rayan Lakes, Siwa Lakes, Abu Zabal Lakes, Wadi El-Natrun Lakes and Solar Lakes. Despite the critical need for lakes and reservoirs evaporation information, no continentally consistent and locally practical evaporation dataset has been produced that can be used in the policy making process at a national scale. In Egypt, water loss due to evaporation process has not been raised as a significant problem. Therefore, the aim of the present study was to estimate the amount of water loss from the largest and most important 6 Egyptian lakes and Nasser reservoir through evaporation and compare it with the supplied water in Egypt.

MATERIALS AND METHODS OF COMPUTATIONS

Six lakes were selected to estimate the surface water loss by evaporation according to their importance. These lakes are: Lake Maryut, Lake Idku, Lake Burullus, Lake Manzalah, Lake Bardawil, Lake Qarun, as well as Nasser reservoir. Original data on evaporation from experimental lakes were provided from published literatures by different authors, as shown in Table (1).

Table (1). Sources of evaporation data in some Egyptian lakes

Lake	Data source
Burullus	**Said and Hussein, 2013**
Manzalah	**Said and Abdel-Moati, 1995**
Bardawil	**Abd-Ellah and Hussein, 2009**
Qarun	**El-Gamal *et al*., 2017**
Nasser	**Hamdan and Zaki, 2016**

In literature, no data were documented on the evaporation rate for Lake Maryut and Lake Idku. In the present work, the evaporation from Lake Maryut and Lake Idku was estimated using the method of **De Bruin and Kejiman (1979)**. The meteorological data such as air temperature and wind over the lakes during 2021 were made available through the Egyptian Meteorological Authority, Cairo, Egypt. The equation is written by **Winter *et al.* (1995)**. Evaporation is estimated based on radiation and heat storage only as shown in the following form:

$$E = 1.26 \frac{\Delta}{\Delta+\gamma}(R_{net}\text{-S})/\lambda$$

Where, R_{net} and S are the net radiation (MJ $m^{-2}day^{-1}$) and lake heat storage change in the interval, λ is the latent heat of evaporation (2.46×106 JKg^{-1}), and Δ is the mean slope of the saturated vapor pressure-temperature curve at the air temperature. The two terms of the slope Δ and psychrometric constant γ are expressed as empirical relation of air temperature **(Yao *et al*., 1996)** in the form:

$$\frac{\Delta}{\Delta+\gamma} = 0.439 + 0.01119T_a \ ; \frac{\gamma}{\gamma+\Delta} = 0.5494 - 0.01119T_a$$

The radiation $R_{net}$is the difference between the incoming net shortwave radiation (R_{ns}) and the outgoing longwave radiation (R_{nl}) according to **Allen *et al*. (1998)**:

$$R_{net} = R_{ns} - R_{nl}$$

We modelled the energy that is taken up by the water body during the warmer months and subsequently released as evaporation during the cooler months by change in water heat storage from one month to the next. We defined a mean monthly water body temperature, T_{wb} as the arithmetic mean of epilimnion (taken as the surface water temperature, T_w) and the hypolimnion temperature, T_b (Lake bottom temperature):

$$T_{wb} = 0.5\ (T_w + T_b)$$

This assumes that in shallow lakes, the water volumes of the epilimnion and hypolimnion are equal. Accordingly, the change in the hypolimnion temperature between one month and the next is the same as that of the epilimnion when $T_w > T_b$ for shallow lakes and negligible for deep lakes (T_b weakly varying), and we computed the mean water body temperature change between month j and $j-1$ from:

$$T_{wb} = T_{w,j} - T_{w,j-1}$$

Which is valid when $T_w = T_b$. The corresponding change in the heat storage from month $j-1$ to j per unit area was computed using the following formula of **Vardvas and Fountoulakis (1996)**:

$$S = C_\rho \rho h \Delta T_{wb}/n$$

Where, C_ρ= 4186 $jKg^{-1}\ C^{-1}$ is specific heat of water; $\rho = 1000$ Kg^{-1} is water density; h is the mean depth of lake (m) and n is the number of days in month.

The De Bruin-Kejiman method was applied and examined by **Said and Hussien (2013)** to calculate the evaporation from Lake Burullus. They concluded that, the results of this method were in good agreement with the calculated evaporation from the Egyptian Mediterranean waters given by **Said (1993)**. The evaporation losses were estimated as the product of the evaporation rate and surface area of each lake.

RESULTS

Lake Maryut

Lake Maryut is one of the four delta lakes of Egypt. It is a shallow, closed and brackish lake with an average depth of about 60cm, located at the southern part of Alexandria (Fig.1). During the last 50 years, the lake's area diminished considerably, partly due to silting and partly to land reclamation projects, and now its area is only 17000 feddans (about 71.4 km^2).

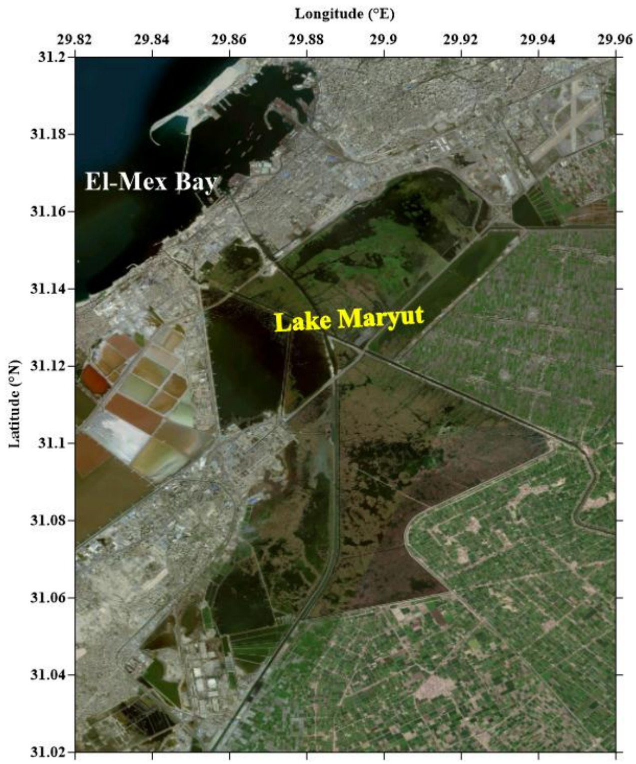

Fig. 1. Lake Maryut

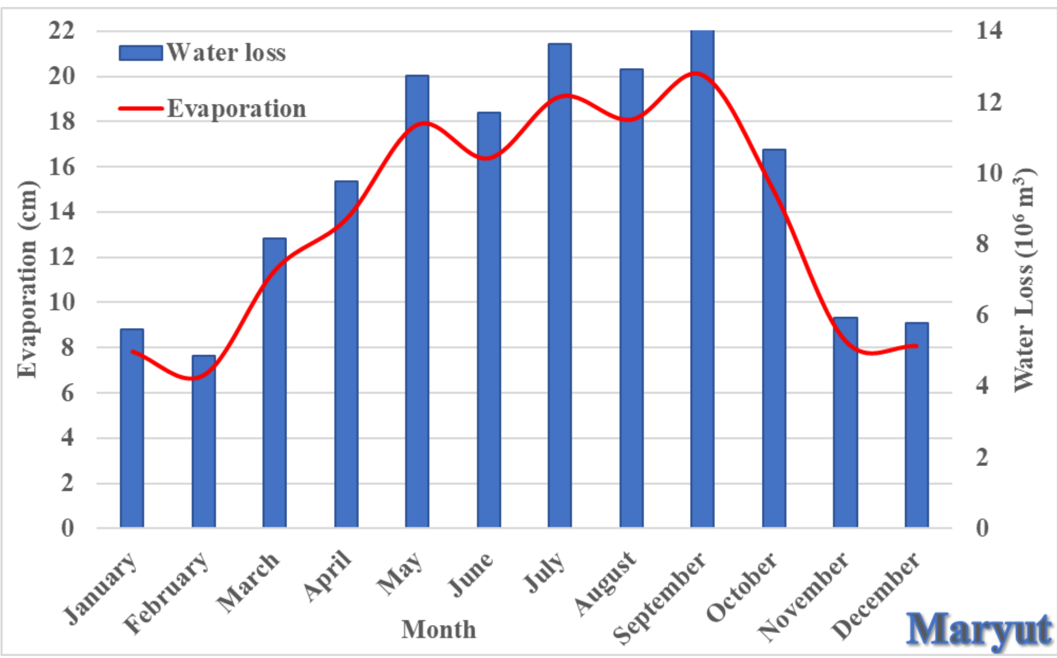

Fig. 2. Monthly evaporation rate and water loss from Lake Maryut during 2021

Evaporation rate and water loss through evaporation from Lake Maryut fluctuate between a minimum of 6.8 cm and 4.86×10^6 m^3 in February and a maximum of 20.06cm 14.32×10^6 m^3 in September, respectively (Fig.2). The annual evaporation rate and water loss are 162.62 cm and 116.11×10^6 m^3.

Lake Idku

Lake Idku is a shallow brackish water lake about 80km to the NE of Alexandria (Fig.3). It has an area of about 126km^2 and a depth between 50 & 150cm, with an average depth of about 90cm. The bay is connected to the Mediterranean Sea through El-Maaddiya outlet (about 2m deep and 20m wide).

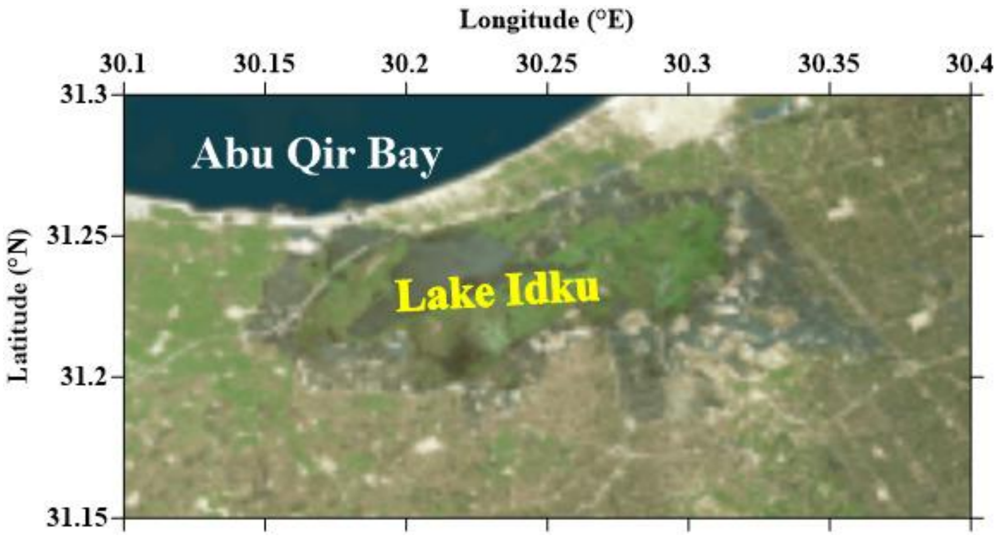

Fig. 3. Lake Idku

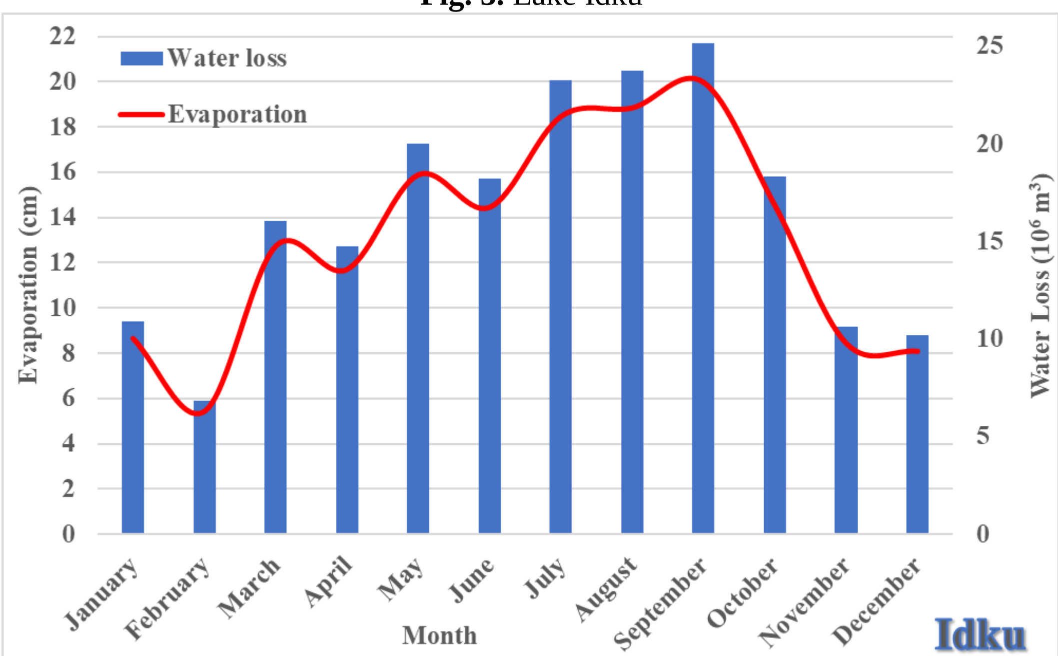

Fig. 4. Monthly evaporation rate and water loss from Lake Idku during 2021

Evaporation rate and water loss through evaporation from Lake Idku fluctuate between a minimum of 5.42cm and 6.83×10^6 m^3 in February and a maximum of 19.98cm 24.17×10^6 m^3 in September, respectively (Fig.4). The annual evaporation rate and water loss are 157.18 cm and 198.05×10^6 m^3.

Lake Burullus

Lake Burullus occupies the central part of the northern Delta. It lies between longitudes 30° 30' & 31° 10'E and latitudes 31° 21' & 31° 35'N (Fig.5). It extends from the East to the West of a shoreline of 150km. The lake is roughly rectangular in shape of about 60- 70km in length, ranging from 6 to 16km, with an average width of about 11km, and a total area of about 462km^2. Its depth varies between 50 and 200cm, with an average depth of about one meter.

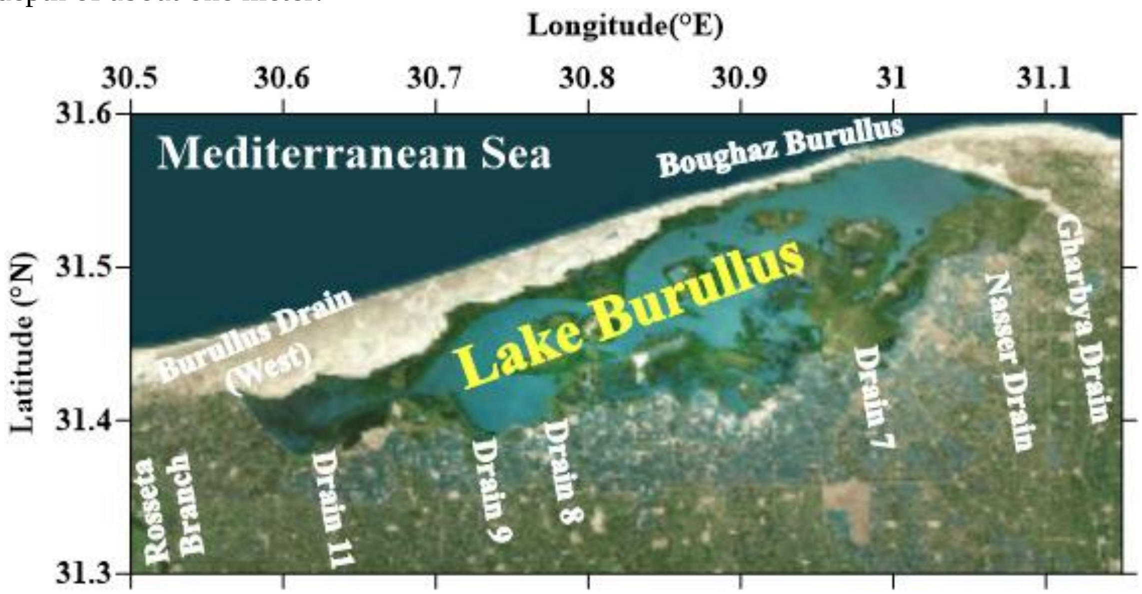

Fig. 5. Lake Burullus

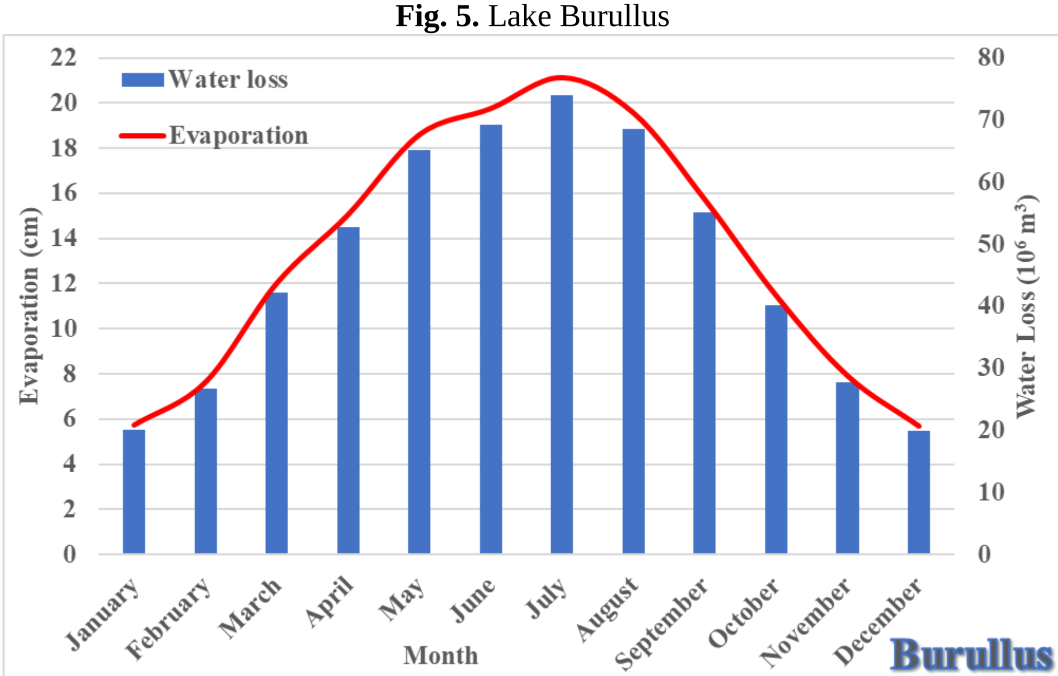

Fig. 6. Monthly evaporation rate and water loss from Lake Burullus

Evaporation rate and water loss through evaporation from Lake Burullus fluctuate between a minimum of 5.69 cm and 19.92×10^6 m^3 in December and a maximum of 21.14

cm 73.99×10^6 m^3 in July, respectively (Fig.6). The annual evaporation rate and water loss are 160.39 cm and 741.00×10^6 m^3.

Lake Manzalah

Lake Manzalah is the largest lake among the northern Delta lakes in Egypt. The lake occupies the northern area between Damietta branch of the Nile and the Suez Canal (long. 31° 45' & 32° 15' E; lat. 31° 00' & 31° 35'N). It is bordered by the Mediterranean Sea to the North, while its southern and southwestern borders are surrounded by cultivated land (Fig.7). The lake is rectangular in shape with a length of about 65km, and its greatest width is approximately 45km. Its area is about 700km^2. The lake is shallow with an average depth of about one meter; 25% of the lake is less than 60cm in depth, 50% within the range of 60-100 cm, while the remaining 25% is more than 100cm deep **(Said, 1992)**.

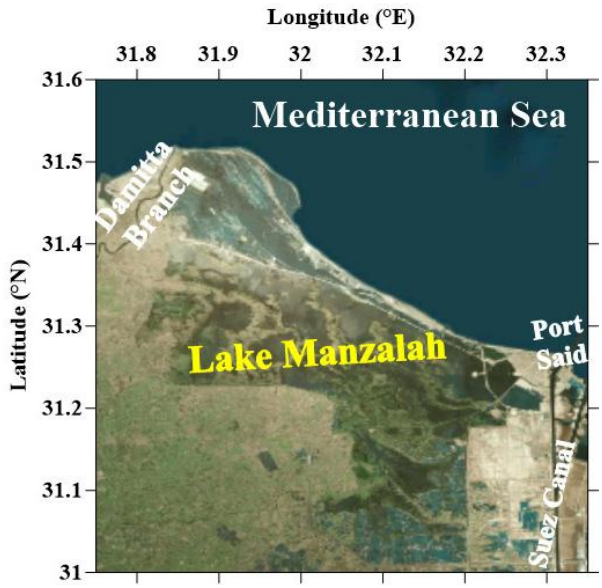

Fig.7. Lake Manzalah

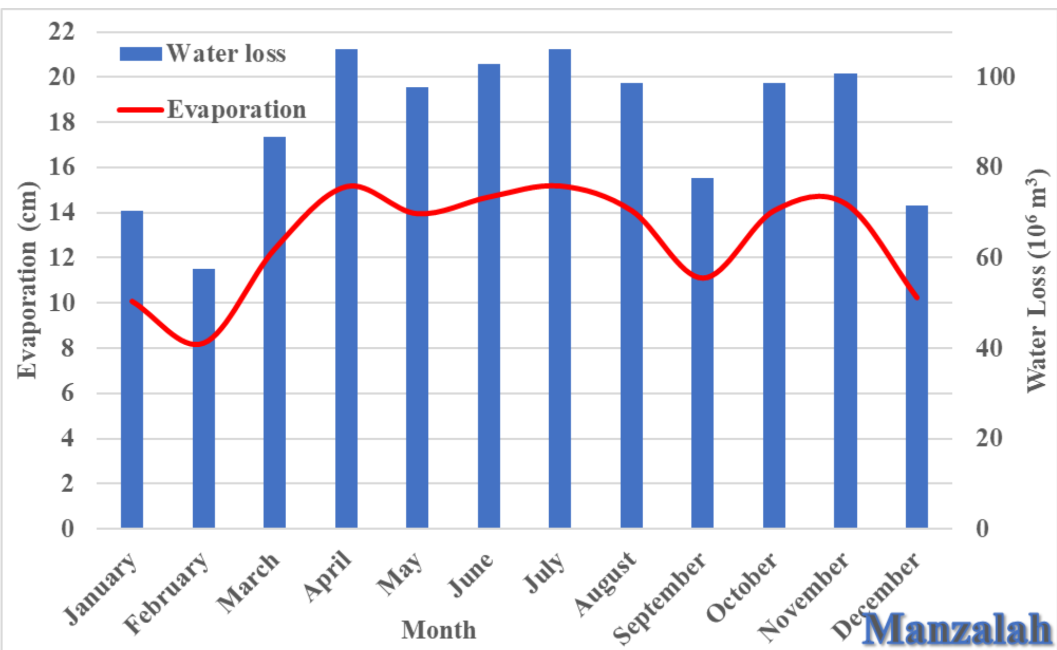

Fig. 8. Monthly evaporation rate and water loss from Lake Manzalah

Evaporation rate and water loss through evaporation from Lake Manzalah fluctuate between a minimum of 8.21cm and 57.5×10^6 m^3 in February and a maximum of 15.19

cm 106.3×10^6 m^3 in July, respectively (Fig.8). The annual evaporation rate and water loss are 153.62cm and 1075.6×10^6 m^3.

Bardawil Lagoon

The Bardawil hypersaline lagoon in the northern Sinai desert is situated between longitudes 32° 40' & 33° 30' E and latitudes 31° 03' & 31° 14' N (Fig.9). It is about 90km long, with a maximum width of 22km and an area of about 650km². It has an average depth of about 150cm. Its continued existence is made possible by maintaining two inlets from the Mediterranean Sea by dredging.

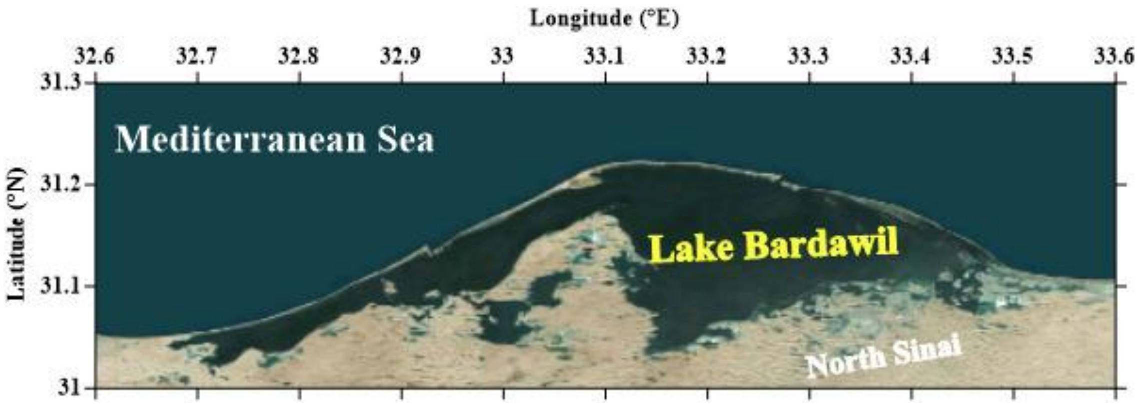

Fig. 9. Lake Bardawil

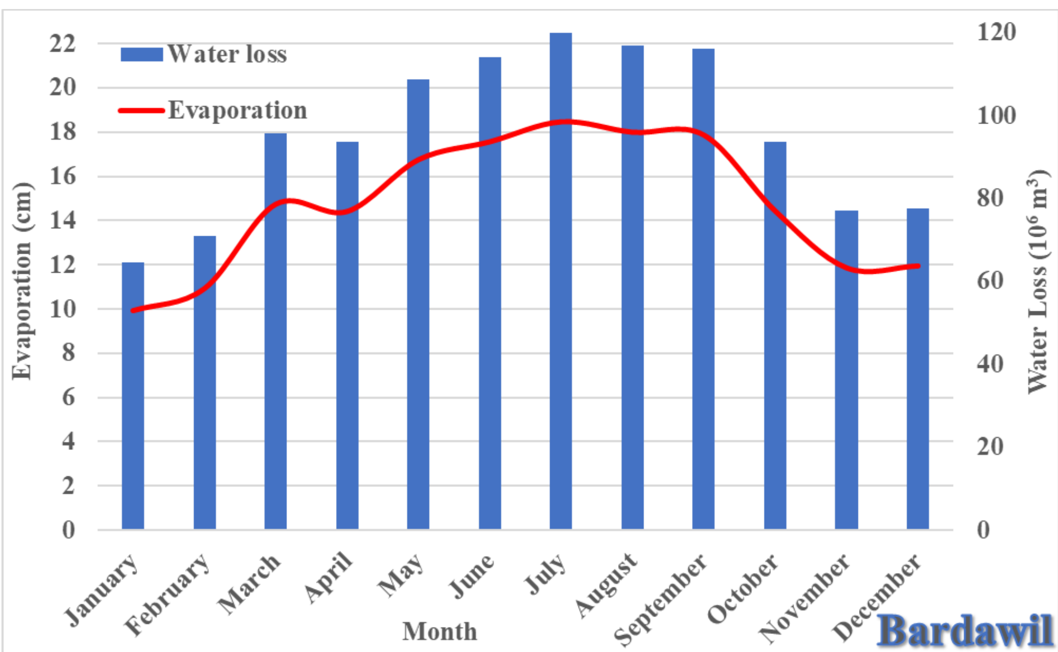

Fig. 10. Monthly evaporation rate and water loss from Lake Bardawil

Evaporation rate and water loss through evaporation from Lake Bardawil fluctuate between a minimum of 9.92cm and 64.48×10^6 m^3 in January and a maximum of 18.45cm 119.93×10^6 m^3 in September, respectively (Fig.10). The annual evaporation rate and water loss are 176.75cm and 1148.88×10^6 m^3.

Lake Qarun

Lake Qarun is a shallow closed lake, located in the north of Fayoum depression between longitudes 30.40° and 30.83°E, and latitudes 29.404° and 29.537° N (Fig.11). It has a rectangular shape with a length of 43km and a width of 5.6km,; its area is estimated at 244.80km^2. The average depth of the lake is about 4.20 meters, while the maximum depth is 9.0 meters in the northern side of the lake. Lake Qarun is currently saline, turbid and without surface outflow. Its salinity has exceeded seawater salinity **(Hassan, 2015)**.

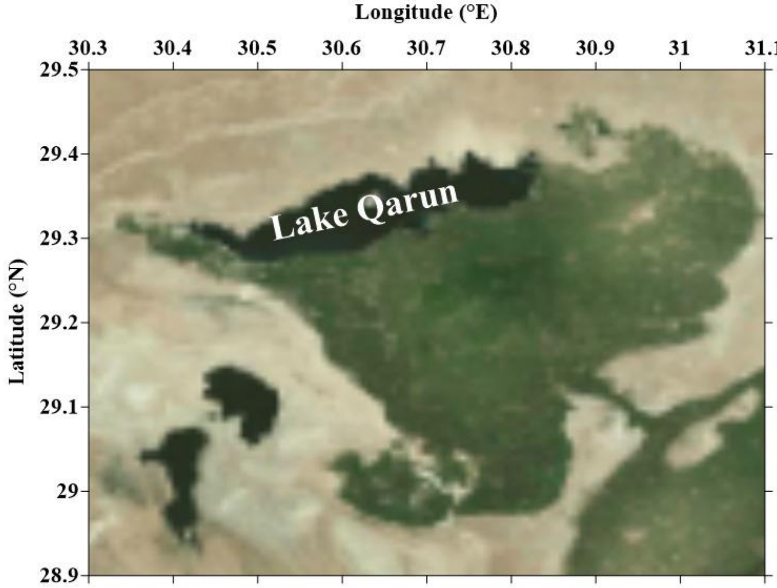

Fig.11. Lake Qarun

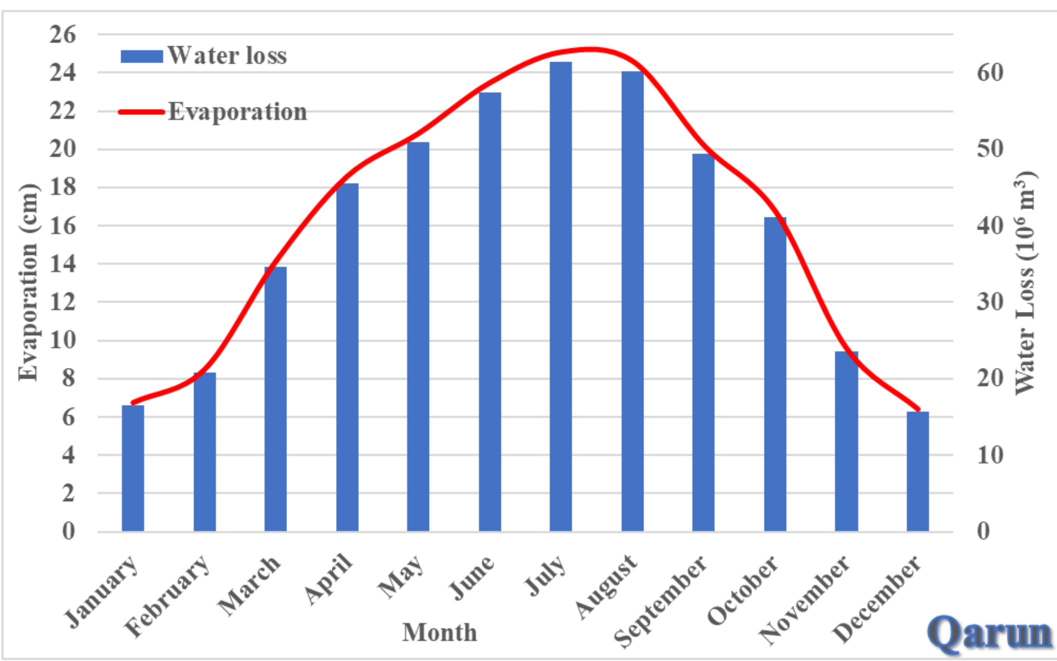

Fig. 12. Monthly evaporation rate and water loss from Lake Qarun

Evaporation rate and water loss through evaporation from Lake Qarun fluctuate between a minimum of 6.43cm and 15.74×10^6 m^3 in December and a maximum of

25.08cm 61.4×10^6 m^3 in July, respectively (Fig.12). The annual evaporation rate and water loss are 195.02cm and 477.41×10^6 m^3.

Lake Nasser

Lake Nasser is one of the largest man-made fresh-water reservoirs in the world. It lies between latitudes 22° 00\` to 23° 58\` N and longitudes 30° 07\` to 33° 15\` E and lies in the extreme southern part of Egypt behind Aswan High Dam (Fig.13). The shoreline of Nasser Lake reservoir is 5416 km in length at 160m level and 7875 km at 180m level. The surface area of its entire reservoir is 3084 km^2 at water level of 160m. It has an area of about 6276 km^2 at water level of 180m (when the reservoir is nearly full) as mentioned in the study of **Jeongkon and Mohamed (2002)**. **Sadek *et al.* (1997)** mentioned that, the total capacity of Lake Nasser is 162.3×10^9 m^3 at the level 182m, with an 85% in Egypt **(Ebaid & Ismail, 2010)**. The lake has an average width of 12km, and maximum width of 60km. The average depth is about 25m, and the maximum depth is 130m **(Elewa, 2006)**.

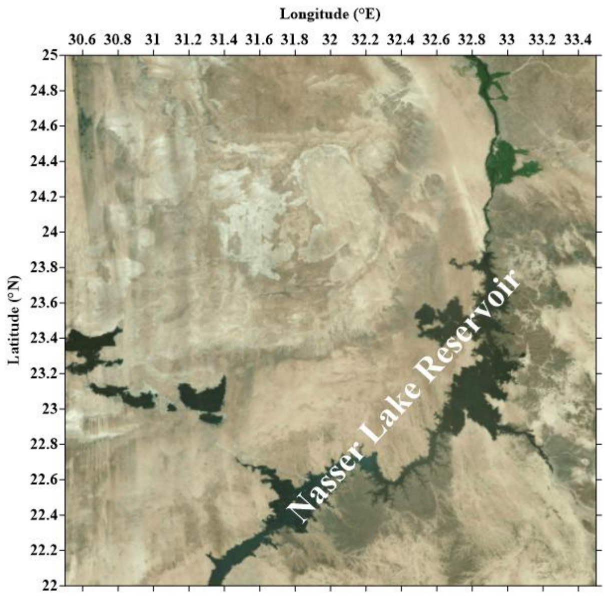

Fig.13. Nasser Lake Reservoir

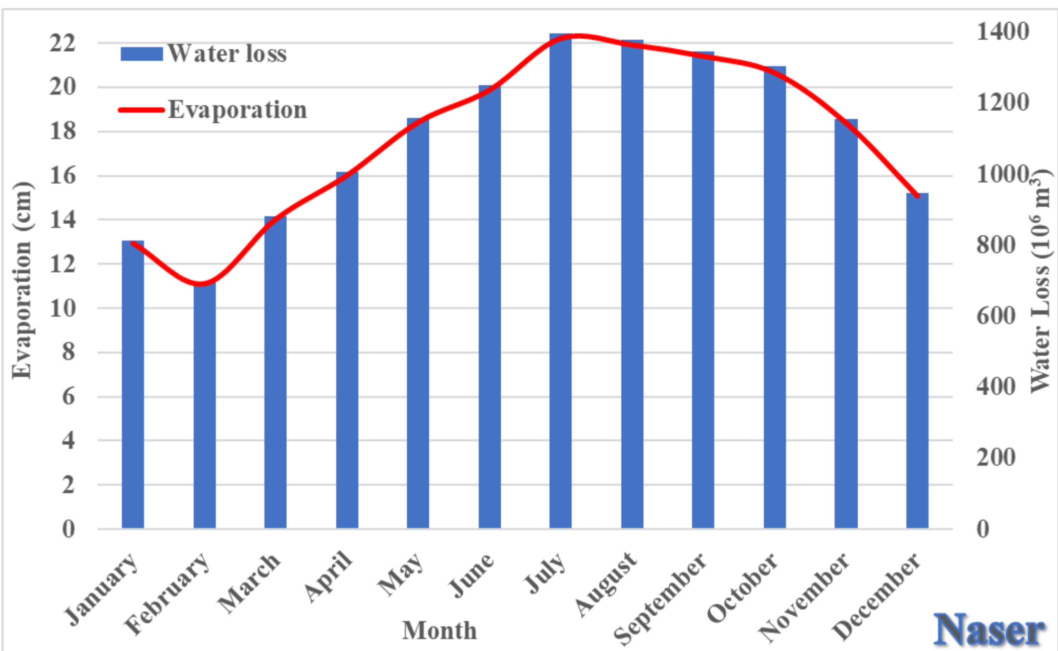

Fig. 14. Monthly evaporation rate and water loss from Lake Nasser

Evaporation rate and water loss through evaporation from Lake Nasser fluctuate between a minimum of 11.12cm 698×10^6 m^3 in February and a maximum of 22.24cm and 1396×10^6 m^3 in September, respectively (Fig.14). The annual evaporation rate and water loss are 212.25cm and 13328×10^6 m^3.

The total surface areas of the 6 Egyptian lakes and Nasser reservoir were 8530.2 km^2, of them 2254.2 km^2 for the 6 lakes and 6276 km^2 for Nasser reservoir (Table 2).

Table 2. Surface areas and water loss through evaporation from lakes and reservoir

Lake	Evaporation (cm/year)	Surface area (km^2)	Water loss (10^9 m^3/year)
Lake Maryut	162.62	71.4	0.116
Lake Idku	157.18	126.0	0.198
Lake Burullus	160.39	462.0	0.741
Lake Manzalah	153.62	700.0	1.076
Lake Bardawil	176.75	650.0	1.149
Lake Qarun	195.02	244.8	0.477
Lakes	1005.58	2254.2	3.757
Nasser Reservoir	212.25	6276.0	13.328
Total	1217.83	8530.2	17.085

Total evaporative loss from water surfaces averages 17.085×10^9 m^3 per year, of which 3.757×10^9 m^3 is from the lakes and 13.328×10^9 m^3 from Nasser reservoir (Table 2). This amount of water loss through evaporation is greater than the 9.6×10^9 m^3 of the ground water; it is greater than the amount of the re-use of agriculture drainage water (13.5×10^9 m^3/year), rainfall (1.3×10^9 m^3) and the destination of sea water (0.35×10^9 m^3). This amount of water loss represents more than 30% of the 55.5 billion cubic meters of allocated water to Egypt per year according to the Nile Water Agreement in 1959.

DISCUSSION AND CONCLUSION

Available water in Egypt through the different water resources is 80.25×10^9 m^3, and the annual water loss from the surfaces of only 6 lakes and Naser reservoir is around 17.085×10^9 m^3 which represents 21% of the total water income of the country. The surface area of the Nile River and Wadi El-Ryan was not included in the present work.

Egypt is not a water-rich country from the perspective of annual water consumption per person. In order to be a water-rich country, annual usable water must be much more than 10^4 m^3 per person **(Avci, 1996)**. In the present study, the total amount of 80.25×10^9 m^3 of income water is divided by the population of the country; according to 2020 census (100×10^6 people), annual consumable water is approximately 802.5 m^3 per person, which is much less than 10^4 m^3.

Shaltout and El-Housry (1997) mentioned in their work that, the annual evaporated water loss from Lake Nasser ranged between 10 and 16×10^9 m^3, which is equivalent to 20– 30% of the Egyptian income from the Nile water and this estimate agrees with the results of the present work.

Gokbulak and Ozhan (2006) estimated the total evaporative loss from fresh water surfaces in Turkey of 6.8×10^9 m^3 per year, of which 2.7×10^9 m^3 is from 129 lakes and 4.1×10^9 m^3 from 223 reservoirs. This amount of water loss was more than one-fifth of the 29.2×10^9 m^3 of water used for irrigation in 1999 **(State Hydraulic Works, 2001)**. **Zhao and Gao (2019)** in their work for estimating the water loss from reservoir by evaporation in the United States they found that, the annual volume of water loss from 721 reservoirs was 33.73×10^9 m^3, representing 93% of the annual public water supply of the United States in 2010.

Since Egypt is not a rich country in terms of water resources, necessary measures should be taken to consider future water requirements of the country and to keep water losses as low as possible. These measures include: selection of deep valleys for building dams and reservoirs to store a greater amount of water with a corresponding smaller surface area, phreatophyte control to minimize water losses in water distribution systems by using better and more reliable facilities, and the use of underground reservoirs if physical and geological conditions permit **(Schwab *et al*., 1993)**. Other measures such as mechanical wind fences could also be established to prevent water loss through evaporation **(Cluff, 1966; Schwab *et al*., 1993)**.

More studies and measurements on water loss through evaporation are needed on the Egyptian Lakes and the Nile River for future water requirements of the country and to keep water losses as low as possible.

REFERENCES

Abd-Ellah, R.G. and Hussein M.M. (2009). Physical Limnology of Bardawil Lagoon, Egypt. American-Eurasian J. Agri.& Environ. Sci., 5(3): 331-336.

Allen, R.G.; Pereira, L.S.; Raes, D. and Smith, M. (1998). Crop Evapotranspiration – Guidelines for computing crop water requirements – FAO Irrigation and drainage Paper No. 56, Rome, Italy.

Avci, I. (1996). Middle east and water problem (Ortado Qu ve Su Sorunu), Cumhuriyet Gazetesi, 11-17 Ocak, Istanbul, Turkey.

Cluff, B. (1966). Research on evaporation reduction relating to small reservoirs. 1963-1965, The Institute of Water Utilization Agricultural Experiment Station, the University of Arizona, Tucson, Arizona.

De Bruin, H.A.R and Kejiman, J.O. (1979). The Priestley-Taylor evaporation model applied to a large, shallow lake in the Netherland. Journal of Applied Meteorology, 18: 898-903.

Ebaid, H.M.I and Ismail, Sh. S. (2010). Lake Nasser evaporation reduction study. J. of Advanced Research, Cairo University, 1: 315-322.

Elewa, H.H. (2006). Water resources and geomorphological characteristics of Tushka and west of Lake Nasser. Egypt Hydrogeol. J.: 14(6): 942-54.

El-Gamal, M.M.A; El-Alfy, K.S.; Abdeallah, M.G.M; Abdel-Haleem, F.S. and El-Hamrawy, A.M.S. (2017). Restoring Water and Salt Balance of Qarun Lake, Fayoum, Egypt. Mansoura Engineering J., 42: 1-14.

Gokbulak, F. and Ozhan, S. (2006). Water loss through evaporation from water surfaces of lakes and reservoirs in Turkey. Official Publication of the European Water Association (EWA), 6 pages.

Goudie, A. S. (2018). Human impact on the natural environment. Hoboken, In: John Wiley & Sons.

Hamdan A.M. and Zaki, M. (2016). Long-Term Estimation of water losses through evaporation from water surfaces of Naser Lake Reservoir, Egypt. International J. of Civil & Environmental Engineering IJCEE-IJENS, 16(5): 13-23.

Hassan, R. M. (2015). Ecosystem restoration using maintenance dredging in Lake Qarun, Egypt. Journal of American Science, vol. 11.

Jeongkon, K. and Mohamed, S. (2002) Assessment of long-term hydrologic impacts of Lake Nasser and related irrigation projects in Southwestern Egypt. Elsevier Science, Journal of Hydrology, 262. 68-83.

Molle, F. and Closas, A. (2020). Co-management of groundwater: A review. Wiley Interdiscip. Rev. Water, 7 (1):1394.

MWRI, (2017). Facts Regarding the Water Situation in Egypt Report.

Sadek, M.F.; Shahin, M.M., and Stigter, C.J. (1997) Evaporation from the reservoir of the high Aswan dam, Egypt: a new comparison of relevant methods with limited data. Theor Appl Climatol., 56: 57-66.

Said, M.A. (1992). Detailed variations in mean temperature and heat content of some Egyptian lakes. Bull. National Inst. Oceanogr. & Fish., ARE,18: 11-23.

Said, M.A. (1993). Evaporation from the Mediterranean shelf waters off the Egyptian coast. J. MAHASAGAR, 26(1):1-7.

Said, M.A. and Abdel-Moati, A.R. (1995). Water budget of lake Manzalah. J. MAHASAGAR, 28(1 & 2): 75-81.

Said, M.A. and Hussein, M.A. (2013). Estimation of Evaporation from Lake Burullus (Egypt) Using Different Techniques. J. King Abdulaziz University (Saudi Arabia), 24 (1): 55-67.

Schwab, G.O.; Fangmeier, D.D.; Elliot, W.J. and Frevert, R.K. (1993). Soil and water conservation engineering. Fourth Edition, John Wiley & Sons, Inc. New York, USA.

Shaltout, M. M.A. and El-Housry, T. (1997). Estimating the evaporation over Nasser Lake in the upper Egypt from Meteosat observations. Adv. Space Res., 19(3): 515-8.

State Hydraulic Works. (2001). 1999 Statistical bulletin (1999 Haritali Istatistik Bülteni), DST Genel MüdürlüQü, G. Yayin No: 991, Grup No: VIII. Özel No: 177, Ankara, Turkey.

Vardvas, I.M. and Fountoulakis, A. (1996). Estimation of lake evaporation from standard meteorological measurements: application to four Australian lakes in different climatic regions. Ecol. Model., 84: 139-150.

Winter, T.C.; Rosenberry, D.O. and Sturrock, A.M. (1995). Evaluation of 11 equations for determining evaporation from a small lake in the north central United States. Water Resources Research, 31: 983-993.

Yao, H.; Terakawa, A. and Chen, S. (1996). Rice water use and response to potential climate changes: circulation and application to Jianghan, China. In Proceedings of the International Conference on Water Resources and Environment research. Kyoto, Japan, 2: 611-618.

Zhao, G. and Gao, H. (2019). Estimating reservoir evaporation losses for the United States: Fusing remote sensing and Modeling approaches. Remote Sensing of Environment, 226: 109-124.