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Reduction of Evaporation from Water Surfaces-Preliminary Assessment for Riyadh Region, Kingdom of Saudi Arabia

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Abstract: The extremely high rate of evaporation from water surfaces in arid and semi-arid regions greatly reduces optimal utilization of water reservoirs. Therefore, applying techniques to reduce evaporation greatly needed. During last decades, a large number of multipurpose dams (258) with overall design capacities of (~898 MCM), were constructed and distributed over the entire Kingdom. Hence, preserving and protecting the stored water dams reservoirs by reducing evaporation is strategic future task of the Saudi government. The present study was conducted for 7 months, from June-December 1998. Experiment was conducted in Riyadh with three US Class-A evaporation pans and a weather station. Fatty alcohol emulsion was selected to reduce the evaporation during summer months in Riyadh. Various concentrations of emulsion substance were used in different pans. First pan (H_0) was filled with water without adding emulsion while in pan (H_1), Fatty alcohols emulsion was added with recommended concentration of (100 g/1000 m^2/day) and similarly in pan (H_2) emulsion was added with double of concentration (200 g/1000 m^2/day). The preliminary results of the study indicated that evaporation rate from surface water was reduced overall up to 47.2 and 50.5% in pans (H_1) and (H_2), respectively as compared to pan (H_0).

Key words: Evaporation reduction, dam water reservoirs, fatty alcohol emulsion, thin invisible layer, Riyadh region evaporation rates, surface water evaporation control

INTRODUCTION

Fresh water resources such as groundwater and surface water in the form of streams and lakes have strategic importance and high economic value for a country. They become even vital when they are scarce and nonrenewable particularly in arid regions.

The Kingdom of Saudi Arabia, due to its geographical location and climatic conditions is characterized by limited renewable water resources. In fact, renewable water resources of the Kingdom are significantly less as compared to non-renewable water resources due to low annual precipitation and therefore, require greater attention for development and management for long term utilization.

Considering the importance of optimal utilization of renewable water resources, Ministry of Water and Electricity (MOWE) has constructed >258 dams with total storage capacities of about (898) (MCM) until the year 2007 and several new large dams are under construction (Ministry of Water and Electricity, 2007).

One of the challenges of water management in arid regions is to reduce the huge amount of water loss through evaporation from water surfaces of dam reservoirs and lakes due to extremely high evaporation rates (Gokbulak and Ozhan, 2006; Craig, 2008).

The rainfall in the Kingdom takes place primarily during winter and spring. However, appreciable summer rains do occur in some parts of the Kingdom. The ambient air temperature varies greatly from season to season and from region to region. Very high temperatures combined with extreme diurnal variations occur throughout the Kingdom. The month of July has the maximum temperature over most of the Kingdom. The lowest relative humidity is generally noted during June and July whereas December and January are the months of maximum relative humidity. Relative humidity of <10% is very common during the summer months. Strong winds associated with storms generally blow during the winter months from December through February.

The dominant climatic features in the Riyadh study area are high mean temperature, low humidity and hot advective winds, resulted relatively high evaporation rates. The climate is very hot in summer (May-September) with temperatures in excess of 45° and <-5° in winter (November-January). During summer months when evaporation rates from water surface may reach their peak up to 18.5 mm day^{-1} during summer.

The present research is focused on selection of best available and most feasible technique considering Saudi Arabian climatic conditions for reduction of evaporation from large surface areas of dam reservoirs and artificial lakes of Kingdom.

In order to reduce the evaporation from water surfaces, several methods were reviewed to select the most feasible method for climatic and geographic conditions of the Kingdom. Major available methods of evaporation reduction from water surfaces of Dam Reservoirs and Lakes as described by GHD Ptv. Ltd (2003), Craig (2008) and CEESU and RWUEI (2002) which are presented as:

Reduce water surface area: Decrease of water surface area as compared to storage capacity of the dam.

Cover water surfaces: A plastic cover or floating substance can be used to act as air cushions around the lake to reduce evaporation.

Use of chemical substances to make a thin film over water surface: Chemical substances such as fatty alcohols can be sprayed periodically on water surface to reduce evaporation.

After a detailed review of the available evaporation reduction methods, surface water cover technique was selected using fatty alcohol emulsion substance to form a thin film over water surface to reduce evaporation (GHD Ptv. Ltd, 2003), (Craig *et al*., 2005). This method has several advantages over other methods. It is economically feasible due to low cost of substance and easily available. It mixes with water easily and when added to large water surface, it forms a thin invisible film that reduces evaporation considerably. It decomposes easily and doesn't dissolve in water. The substance can be applied using boats or spry planes.

There are several methods to measure evaporation from free water surfaces through US Weather Class A Pan), or more accurately by using energy balance equations (Craig, 2008). Due to several factors including air movement and fluctuations of water surface, which affect the accuracy of measurement of evaporation depth therefore, standard and well recognized method of (US Weather Class A Pan) was selected for the present study.

The present pilot study was conducted to measure the reduction of evaporation on relatively small and controlled water surface of three Pans (US Weather Class A Pan) with continuous measurement of air temperature, relative humidity, wind velocity and evaporation rates and evaluated the results in terms of efficiency in reducing evaporation. The two Pans were added with fatty alcohol emulsion substance as thin film on water surface to reduce evaporation.

Based on Material Safety Data Sheet (MSDS), the substance does not have any harmful effects on human beings, animals or plants however, further study is required to determine the potential environmental, health and ecological impacts of the substance on aquatic animals and plants.

MATERIALS AND METHODS

The pilot study was conducted at Riyadh, Saudi Arabia with the help of a fully operated meteorological station with sensors to measure sunshine hours, air temperature, wind velocity and relative humidity. Three US Weather Class-A Pans were used with an accurate measuring tool to measure daily water depth in the Pans. A protection cover was constructed to protect the equipments from birds and other animals.

The amount of fatty emulsion added to the three evaporation Pans was calculated and applied to each Pan. No substance was added to Pan (H_0) to measure natural evaporation rate due to ambient conditions and for comparison.

In Pan (H_1), 100 mg of fatty emulsion was added to 1000 m^2 of water surface per day, to make the effective substance in Pan (H_1) is 0.117 g day^{-1}.

As for evaporation Pan (H_2), the calculated amount of fatty emulsion was doubled up to 200 g/1000 m^2 of water surface a day. Thus the effective substance was 0.234 g day^{-1}.

As the total consumption of effective substance is very small (0.351 g day^{-1}) therefore, emulsion was prepared for entire week then mixed with water to facilitate the process of measuring the appropriate amount. Duration the entire study period (June-December 1998), fatty emulsion was sprayed daily in two evaporation Pans H_1 and H_2 and meteorological parameters including air temperature, relative humidity, wind speed and sunshine hours as well as water levels in three Pans were measured. The standard quality control procedure was strictly followed and maintained during measurements of the readings for accuracy and consistency of the results throughout the duration of the pilot study. All the Pans were cleaned regularly to remove sediments from pans, if any.

RESULTS AND DISCUSSION

The results of the study indicated that air temperature ranges from 15.7-40.9°C with average of 30.7°C, while wind velocity ranges from 3.0-13.9 km h^{-1} with average of 6.7 km h^{-1}. The relative humidity ranges from 6.4-54.1% with average of 13.8%. Similarly, the daily Pan Evaporation rates range from 3.5-21.6 mm day^{-1} with average of 11.5 mm day^{-1}. The Pan Evaporation rate

Table 1: Summary of the experiment results of the daily reduction of Pan evaporation rates for different months

Months	Pan evaporation depth (H_o) (mm)	Pan evaporation depth (H_1) (mm)	Pan evaporation depth (H_2) (mm)	E_R (H_o-H_1) (%)	E_R (H_o-H_2) (%)
June	15.31	9.86	8.84	35.6	42.2
July	16.11	9.05	8.85	43.8	45.0
August	15.19	9.05	8.81	40.4	42.0
September	12.51	7.17	6.48	42.7	48.2
October	8.99	4.25	4.12	52.7	54.1
November	6.02	2.70	2.53	55.1	58.0
December	5.13	2.05	1.85	60.1	64.0
Average	11.32	6.30	5.93	47.2	50.5

reached its peak in July and it reached 21.64 mm day^{-1}. Table 1 shows the daily average evaporation rate for 7 months from June to December.

The daily average Pan Evaporation rate for 4 summer months (June, July, August and September) was measured as 15.3, 16.1, 15.2 and 12.5 mm day^{-1}, respectively. Thus, first four months (June to September) witnessed the highest evaporation rates due to high temperature and low humidity.

The relationship of air temperature, mean wind velocities and relative humidity with the evaporation was determined with the help of simple regression analysis of daily observed data. A simple regression model for best fit of observed data for daily air temperature and daily evaporation depth (mm) was developed as in Fig. 1.

The model indicated that there is a direct correlation between air temperatures with the daily pan evaporation rates. Similarly, a simple regression model for best fit of observed data for mean wind velocity and daily evaporation depth (mm) was developed as in Fig. 2.

The model indicated that there is a direct correlation between mean wind velocity with the daily pan evaporation rates. In addition, a simple regression model for best fit of observed data for daily relative humidity and daily evaporation depth (mm) was developed as in Fig. 3.

The model indicated that pan evaporation rates decreases as humidity increases and that there is a inverse correlation between average daily relative humidity with the daily pan evaporation rates. The results of the pan evaporation control experiment after adding fatty emulsion solution with different concentrations and without application in three different evaporation pans from June-December is presented in Fig. 4.

The results indicated a significant reduction in evaporation in the range of 3.1-7.3 mm in average daily evaporation depths (Pans H_1 and H_2) as compared to open surface evaporation (Pan H_0). This reduction in evaporation is primarily due to application of evaporation reducing substance (fatty emulsion), which was added to the H_1 and H_2 Pans.

A simple statistical analysis was performed to elaborate the comparison between evaporation depths in percentages between (H_0-H_1) and (H_0-H_2) with the help of following equation. Figure 5 shows the weekly average reduction of evaporation depths in percentages to show the significant differences during summer and winter months.

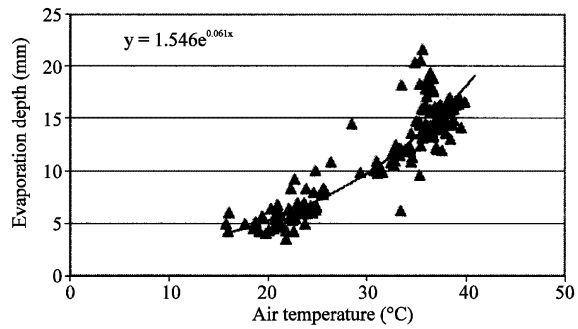

Fig. 1: A simple regression model for daily air temperature and daily evaporation depth (mm)

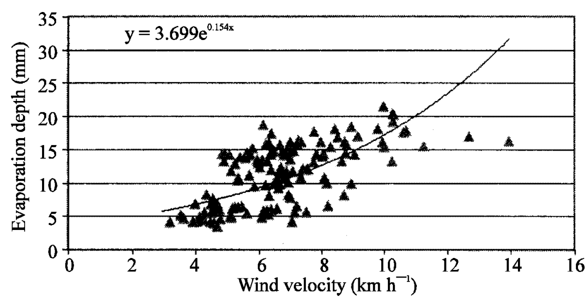

Fig. 2: A simple regression model for mean wind Velocity and daily pan evaporation depth (mm)

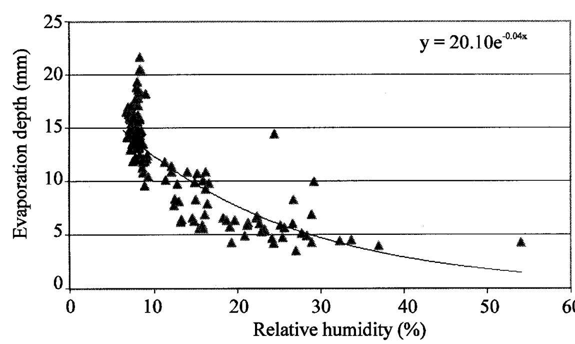

Fig. 3: A simple regression model for relative humidity and daily pan evaporation depth (mm)

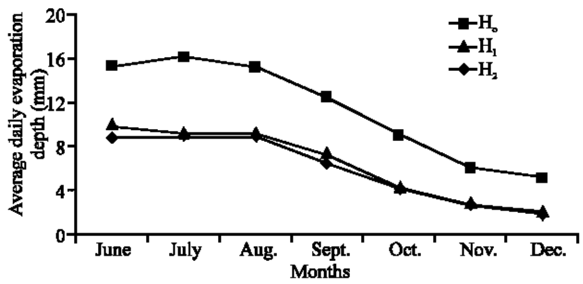

Fig. 4: Average daily evaporation depth (mm) measured for three evaporation pans (H_0, H_1 and H_2)

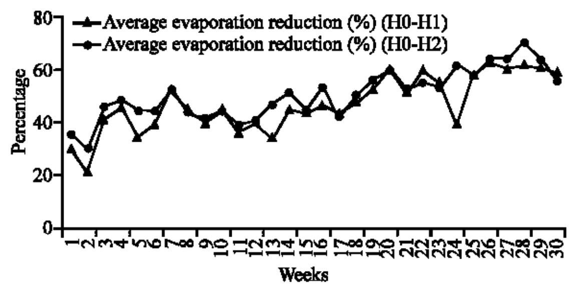

Fig. 5: Average weekly evaporation reduction (%) from evaporation pans (H_0.H_1) and (H_0.H_2)

$$R = \frac{H_i - H_{i+1}}{H_1} \times 100$$

Where:

R = Percentage reduction of evaporated water depth (mm)

i = Pans 0, 1 and 2

Similarly daily average gross evaporation rates for different months for three Pans were compared and the evaporation reductions percentages were calculated. Table 1 shows that the average daily average gross evaporation rates and percentage of reduction of evaporation rate for different months for three Pans.

The pan evaporation rates are smaller in winter as compared to the summer months. In general, evaporation rate from pan H_1 is reduced by 47.2 as compared to pan H_0 when the recommended concentration was applied. Similarly, as for pan H_2 (twice the recommended concentration), we have noted even higher evaporation reduction about 50.5% as compared to pan H_0. In addition, evaporation rate in pan H_2 is less by 3.3% as compared to pan H_1 (which contains the recommended concentration). These findings confirmed that there is a significant reduction in evaporation from free water surfaces when we applied the fatty alcohol emulsion and it is highly feasible and cost effective to use the substance to reduce evaporation.

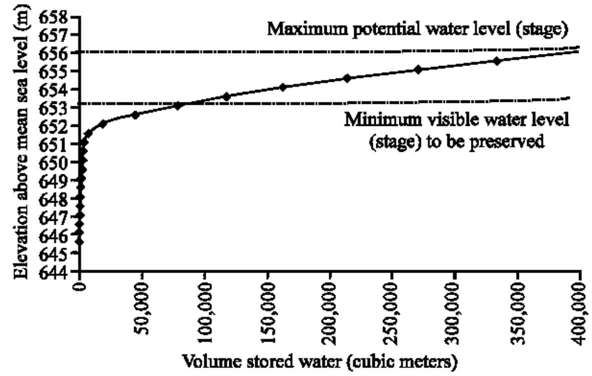

Fig. 6: Stage-volume cure for Al-alb Dam, Riyadh, Saudi Arabia

Case study-Al-Alb Dam, Dariyah, Riyadh: As part of the study, the feasibility of application of evaporation reduction technique on large scale to reduce the water loss through evaporation from water surfaces of large dam reservoirs was analyzed. Al-Alb-Dam located in Riyadh region was selected as case study. Al-Alb Dam is a concrete dam with about 200 m in length, height of 9.5 m and having a storage capacity of about 3 million m^3. The dam was constructed for flood control and recharge of underlying alluvial aquifer. The design data for stage-area-volume for the dam was analyzed and a stage-volume curve is prepared to calculate the potential quantity of water could be preserved as in Fig. 6.

The stage-volume curve indicates that there is about 100,000-400,000 m^3 of stored water in the dam reservoir has been subjected to evaporation and lost during raining season. Therefore, if we apply the evaporation reduction technique, we will be able to preserve about 50,000-200,000 m^3 of water which could be used for agriculture or municipal use.

CONCLUSION

As the population is growing in the Kingdom, the demand for water also increases and therefore, the economic value also increases. The government of Saudi Arabia is highly committed and has strategic plans for storage and maximum utilization of rainwater by building dams. Protecting the stored water in dam reservoirs from evaporation remains an integral part of sustainable planning, especially during the summer hot months, when temperature is high and humidity is low, which leads to extremely high rate evaporation from water surfaces. Fatty alcohol emulsion is one of most feasible and cost effective evaporation retardant which reduces evaporation significantly. The present study has confirmed that Fatty emulsion produces an invisible thin film over water surface that significantly reduces evaporation. The pilot study was conducted to demonstrate the effectiveness of evaporation reduction on US Weather Class A pans adding fatty alcohol emulsion of two different concentrations of 100 and 200 mg/1000 m^2/day. The study concluded that evaporation was reduced up to 47-50% as compared to without addition of emulsion. Therefore, the researcher believes that it is highly feasible and cost effective to apply the present evaporation reduction technique on a large scale to a large number of dam reservoirs of the Kingdom to reduce the water loss through evaporation from water surfaces.

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