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# Evaporation from the Coastal Water of the Central Part of the Gulf

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ABSTRACT. Monthly mean evaporation from the central part of the Gulf is estimated by the aerodynamic method using meteorological and oceanographic data collected in the region during the period 1981-1982. The mean annual evaporation is 201.6 cm with its highest value in June and lowest in January / February.

Evaporation is one of the prime causes of density variation of the water of the Gulf and hence of its pressure gradient which is considerd as an important factor in the determination of water circulation in the Gulf. Evaporation has also profound effects on the water and salt balances in the Gulf and is one of the controlling factors in the process of water exchange with the Gulf of Oman through the Strait of Hormoz. The main axis of the Gulf extends about 990 km in the SE - NW direction between latitudes 24°00, 31°15 N and longitudes 48°00′, 56°20′ E (Fig. 1).

The area and volume of the Gulf are estimated as $2.4 \times 10^{11}$ $m^2$ and $8.6 \times 10^{12}$ $m^3$ respectively, which corresponds to an average depth of about 36 m. Evaporation was estimated by the aerodynamic method using two sets of observations. The first set was taken during 1981 at the meteorological station in Doha, Qatar. (Lat. 25° 16′ N, Long 51° 30′ E). The second set was observed in 1982 at the meteorological station in Manama, Bahrain (Lat. 26° 16′ N, Long. 50° 37′ E). Both stations have a long fetch over the Gulf water (400 km) for northerly and easterly (400 km) winds, while southerly and westerly winds have a long path over the continent. The most dominant wind direction is the north westerly one. The meteorological parameters namely wind speed and direction, humidity, air temperature and atmospheric pressure were measured every 3 hours by standard equipment at 10 m above the mean sea level.

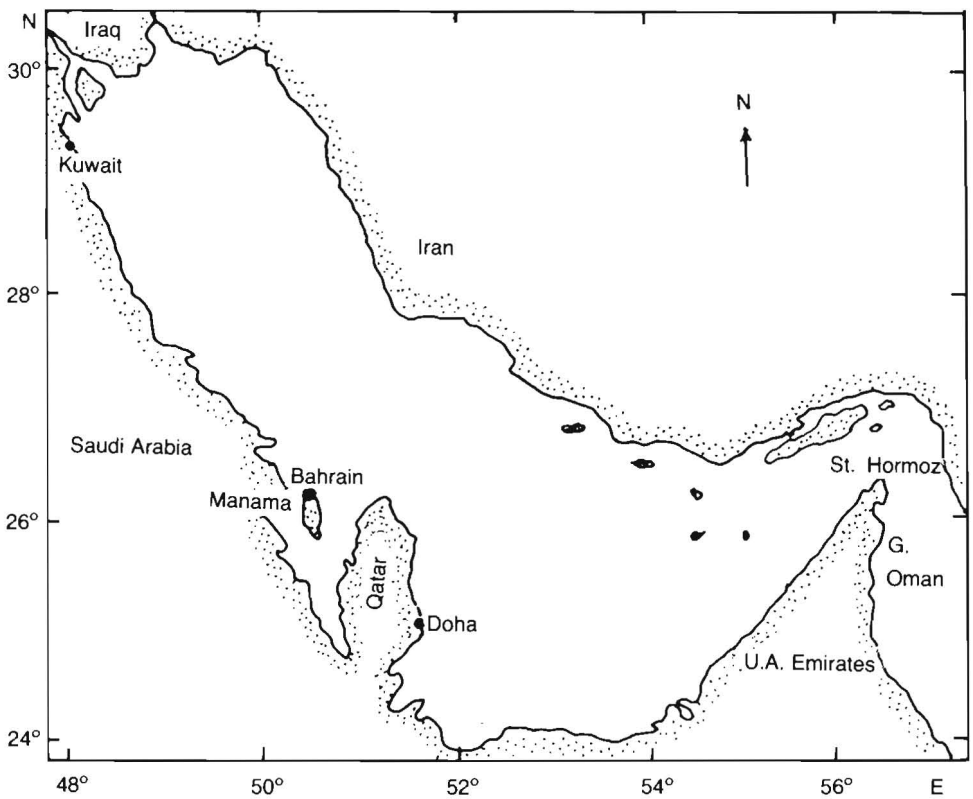


**Fig. 1.** Area of investigation.

## Method

Evaporation from the water of the coastal central region of the Gulf is estimated by the bulk aerodynamic approach. This approach has been considered as a reliable method for estimating evaporation (Sverdrup 1937, Anderson *et al.* 1950, Anderson and Smith 1981, Meshal *et al.* 1984). Evaporation can be found from the calculation of the humidity flux by an equation of the form (Friehe and Schmitt 1976, Esbensen and reynolds 1981):

$$E = C_e \bar{U}_z (\bar{Q}_o - \bar{Q}_z) \quad (1)$$

where E is the humidity flux (g $m^{-2}$ $s^{-1}$), $C_e$ is the dimensionless coefficient of humidity transfer, $U_z$ is the mean wind speed (cm $s^{-1}$) at height z above the sea surface, and $Q_o$ and $Q_z$ are the mean density of water vapour (g $m^{-3}$) of the air saturated at the sea surface temperature and of the air at height z respectively. The

reported values of the coefficient $C_e$ varied from $1.0 \times 10^{-3}$ to $1.6 \times 10^{-3}$ (Deacon and Webb 1962).

However, the review of the relevant literature shows that the most acceptable and reliable value of $C_e$ is $1.3 \times 10^{-3}$ (Pond *et al.* 1971, Coantic 1974 and Anderson and Smith 1981). When this numerical value of $C_c$ is inserted in equation (1) and the units of E are converted from g $m^{-2}$ $s^{-1}$ to cm/day, the equation becomes:

$$E = 1.123 \times 10^{-2} \quad \bar{U}_z (\bar{Q}_o - \bar{Q}_z) \qquad (2)$$

The three - hourly meteorological observations collected at each station were averaged over the day and were then used to calculate the daily coastal evaporation by equation (2). Evaporation in each month was obtained from the summation of its daily values. The monthly evaporation values at Doha and Manama, were averaged to give the monthly mean value for the region (Table 1).

## Results

The average meteorological conditions in the region are studied by examining the mean monthly meteorological parameters observed at Doha, Qatar over an eight-year period (1975-1981) and at Manama, Bahrain over a three year-period (1982-1984). Table (1) illustrates that the mean values of wind speed are low and show only a weak seasonal variations, the difference between the maximum and the minimum speed being less than 2.0 m $s^{-1}$.

**Table 1.** Monthly mean values of the meteorological parameters in the region averaged from observations collected at Manama, Bahrain (1982-1984) and Doha, Qatar (1974-1981).

| Month | $\bar{U}$ m/sc | Ta °C | $\bar{Q}_z$ $gm^{-3}$ °C | Ts $gm^{-3}$ | $\bar{Q}_o$ $gm^{-3}$ | $\triangle Q$ $gm^{-3}$ |
|---|---|---|---|---|---|---|
| January | 5.2 | 17.6 | 10.6 | 17.7 | 15.1 | 4.5 |
| February | 5.1 | 18.5 | 11.2 | 18.9 | 16.2 | 5.0 |
| March | 5.2 | 21.4 | 12.2 | 21.3 | 18.7 | 6.5 |
| April | 4.8 | 25.9 | 13.3 | 25.6 | 23.8 | 10.5 |
| May | 4.9 | 30.0 | 14.8 | 28.8 | 28.5 | 13.7 |
| June | 5.8 | 32.4 | 16.6 | 30.8 | 31.7 | 15.1 |
| July | 4.8 | 33.3 | 19.2 | 31.8 | 33.5 | 14.3 |
| August | 5.1 | 33.5 | 20.9 | 32.5 | 34.7 | 13.8 |
| September | 3.9 | 32.2 | 21.7 | 32.2 | 34.2 | 12.5 |
| October | 4.0 | 29.4 | 18.6 | 29.7 | 29.9 | 11.3 |
| November | 4.5 | 24.7 | 14.6 | 25.3 | 23.4 | 8.8 |
| December | 4.9 | 20.4 | 12.3 | 20.9 | 18.2 | 5.9 |

$\bar{U}$ = wind speed, Ta = air temperature,
$Q_z$ = humidity at air temperature Ts = sea-surface temperature,
$Q_o$ = saturated humidity at sea surface temperature, $\triangle Q = Q_o - Q_z$

The humidity is low in winter and then increases steadily until it reaches its maximum value in autumn (September). The temperature of the coastal water in the region are slightly higher than the air temperature during the period from October through February while the reverse occurs during the remaining months of the year. The maximum sea surface temperature of 32.5°C is reached in August and the minimum of 17.7°C is observed in January reflecting the big annual temperature range of 14.8°C.

The monthly mean evaporation from the coastal water of the region (Table 2) is high in summer and reached its maximum value of 29.3 cm in June and then decreased during autumn and winter to its minimum of 8.1 in February depending on location. The annual evaporation from this region of the Gulf is estimated as 201.6 cm.

**Table 2.** Monthly evaporation from coastal water near Manama, Bahrain and Doha, Qatar. The last column shows their monthly mean value.

| Month | Evaporation (cm) | | | |
|---|---|---|---|---|
| | **Manama** | **Doha** | **Mean** | **S.D.** |
| January | 8.7 | 8.1 | 8.4 | 0.3 |
| February | 8.8 | 7.4 | 8.1 | 0.7 |
| March | 11.5 | 11.7 | 11.6 | 0.1 |
| April | 16.3 | 17.8 | 17.1 | 0.8 |
| May | 21.9 | 24.1 | 23.0 | 1.1 |
| June | 30.1 | 28.5 | 29.3 | 0.8 |
| July | 22.7 | 24.1 | 23.8 | 1.1 |
| August | 24.1 | 24.9 | 24.5 | 0.1 |
| September | 15.8 | 16.7 | 16.3 | 0.5 |
| October | 15.6 | 15.5 | 15.6 | 0.1 |
| November | 15.2 | 12.2 | 13.7 | 1.5 |
| December | 10.0 | 10.3 | 10.2 | 0.2 |
| Sum | 200.4 | 201.3 | 201.6 | |

The Gulf lies in an arid climatic zone where the yearly precipitation ranged between 10 and 55 mm averaged over the period 1972-1977 (Meteorology Department, Doha, Qatar).

The runoff sources are the inflow of fresh water from river Shatt Al-Arab as well as the small Iranian rivers. The discharges of these rivers reach their maximum in the period from March to May and their minimum during the period from

August to December. The annual estimates of fluxes vary considerably from a minimum of about $5 \times 10^9$ $m^3$ in some years to a maximum of $10 \times 10^{10}$ $m^3$ in others (Sudgen 1963, Hartmann, *et al.* 1971 and Ezzat 1985). These quantities of fresh water would cover the surface area of the Gulf by a layer of 2 cm and 40 cm thickness respectively depending on the amount of the influx from the rivers. It follows that there is a net loss of fresh water from the Gulf since evaporation exceeds rainfall and runoff. The net loss of fresh water from the Gulf must be compensated by a differential flow from the Gulf of Oman through the Strait of Horoz. This flow is vital to the renewal of the Gulf water.

As far as we know, no previous studies have been made to estimate evaporation from the coastal water of the region. On the other hand, Privett (1959) calculated evaporation from the open water of the Gulf as 144 cm/year which is much smaller than the value reported in the present study. (201.6 cm/year). Moreover, the time of occurence of the extreme values of evaporation differs in the two studies. Privett's highest and lowest evaporation values are in December and May while in our study they occur in June and January respectively.

The discrepancy between the two results is expected and may arise from the fact that Privett's estimation is based on observation collected in the open water of the Gulf while the data used in the present study is obtained from the coastal region. Hence, it may be considered that Privett's value represents evaporation from the open water of the Gulf. Evaporation from coastal water in this region is expected to be higher than from open water because the surface temperature of the shallow coastal water is higher than that of the open water by an average of 0.5°C in winter and 1.6°C in summer. This leads to an increase in the value of $Q_o$ used in equation (2) and hence to an increase in evaporation. Moreover coastal area are more subject to dry air comming from the continent than open water. Evaporation from a natural water body is mainly controlled by wind speed (U) and by the difference between the values of the vapour pressures at sea surface and at air temperatures ($\triangle$ Q). The meteorological observations collected in this region over the eight - year period showed that the values of U and $\triangle$ Q are higher in summer than in winter (Table 1). Accordingly, it is expected that in summer the Gulf loses more water through evaporation than in winter. The same trend was observed in the relatively larger water body, the Red Sea, by Krummel (1911); Vercelli (1925); Yegorov (1950) and Neumann (in Morcos, 1970) who reported maximum evaporation in summer and minimum in winter.

Behairy *et al.* (1981a,b) found that, for the open water of the central part of the Red, the highest value of evaporation occured in November and the lowest in September while for the coastal water the highest evaporation was in spring/ summer and the least was in autumn/winter.

The results of an earlier study in the central zone of the Red Sea (Meshal *et al.* 1984) showed that the annual evaporation from the open water was only about

70% of that in coastal waters. If this conclusion can be applied to this region of the Gulf, there would be no discrepency between the annual values reported here and those of Privett.

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# البخر من الجزء الأوسط للخليج

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المكتب الإقليمي لليونسكو الدوحة ـ قطر
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حُسِبَ المتوسط الشهري لمقدار المياه المتبخرة من الجزء الأوسط للخليج بطريقة ديناميكية الهواء وباستعمال بيانات عن الأرصاد الجوية في المنطقة جمعت خلال ثمان سنوات متصلة (١٩٧٤ ـ ١٩٨١) بالإضافة إلى قياسات لدرجة حرارة مياه سطح البحر. وقد وجد أن مقدار البخر السنوي من هذه المنطقة من الخليج يبلغ ٢٠٣,٧ سم، وأن البخر قد وصل إلى أعلى قيمة له خلال شهر حزيران (يونيه) وإلى أقل قيمة له خلال شهر كانون الثاني (يناير).

وعند تطبيق مقدار البخر السنوي الذي توصلنا إليه لحساب مقدار الزمن الذي ينخفض خلاله تركيز الملوثات التي قد تتواجد في الخليج إلى ١٠٪ من تركيزها الأصلي، وجد أنه يعادل ٣,٩ سنة.