COMPARISON OF EVAPORATION RATES BETWEEN COASTAL AND OPEN WATERS OF THE CENTRAL ZONE OF THE RED SEA

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ABSTRACT

Monthly evaporation was estimated from coastal and open sea waters in the central zone of the Red Sea betwen latitudes 21°N and 22°N. The aerodynamic method was used to calculate evaporation using two sets of observations collected at a coastal station situated on the Eastern Coast of the Red Sea and in the open waters.

The annual evaporation from coastal water was 205 cm with its highest in May and lowest in September/October. For open water it was 144 cm with maximum in November and minimum in September. Monthly evaporation values for coastal and open waters were almost the same during autumn but differed significantly in spring. For coastal waters the continental influence was obviously reflected in the values of vapour pressure and friction velocity with subsequent effect on evaporation.

The study showed that the product of vapour pressure deficit and the friction velocity was the major factor controlling evaporation, while the other elements in the aerodynamic formula used, had a negligible effect. Hence a simple evaporation equation was deduced and its reliability was tested using data from different climatic zones. The results obtained were in excellent agreement with those obtained from the more complex equation.

INTRODUCTION

Morcos (1970) gave a comprehensive review of the few attempts that have been made to estimate evaporation from various parts of the Red Sea. However, the reported values which represent only evaporation from scattered areas of the Red Sea are inconsistent and full of gaps in their temporal and spatial distributions. Moreover, these values were calculated by different methods using observations taken either on coastal or open waters. It is well known that evaporation values from coastal and open sea waters are generally different. However, the quantitative difference has not been estimated before in any part of the Red Sea because of the use of different approaches and techniques in different zones.

The present study is devoted to the comparison of coastal and open sea evaporation estimated by the same method and at the same latitudes. For this purpose, monthly evaporation from coastal and open sea waters were computed by the aerodynamic method using two sets of observations. The first set was taken on the Eastern Coast of the Red Sea near Jeddah (lat. 21° 30′N, long. 39° 12′E) during the whole year of 1973. The second set of observations was collected for one year during 1977/78 on board the R/V SOELA in the open sea at 21 stations covering the whole width of the Red Sea between the parallels 21°N and 22°N (Fig. 1). Sea surface temperature and meteorological parameters were continuously recorded by standard instruments placed at the coastal station and on board the vessel. Details of the observations are reported in previous works (Red Sea Commission, 1978; Behairy et-al, 1981 a, b).

METHOD OF ESTIMATION OF EVAPORATION

The aerodynamic approach was used to estimate monthly evaporation from coastal and open waters. From the several evaporation equations developed by different authors, Sverdrup's (1937) equation was chosen to estimate evaporation since it gave reliable results (Marciano and Harbeck, 1954; Meshal, 1973). The equation can be written as:

$$F = \frac{0.622\, \varsigma\, ku^* \,(e_o - e_z)}{P\left(\ln \frac{z + z_o}{d + z_o} + \frac{kdu^*}{D}\right)} \qquad \ldots\ldots\ldots (1)$$

where

- F rate of evaporation per unit area $(g\ cm^{-2}\ s^{-1})$
- ς density of the air = 1.2×10^{-3} $(g\ cm^{-3})$,
- k Von Karman's constant = 0.4,
- e_z vapour pressure (mb) at height z,
- e_o correct saturation vapour pressure (mb) at sea surface temperature,
- D coefficient of vapour diffusion = 0.25 $(cm^2\ s^{-1})$,
- u^* friction velocity $(cm\ s^{-1})$,
- z_o roughness length = 0.6 (cm),
- P atmospheric pressure (mb),
- d thickness of the laminar layer defined by Von Karman (1934) as: $d = 30V/u^*$. Where V is the kinematic viscosity of the air = 0.15 $(cm^2\ s^{-1})$ and,
- z height of observation above the sea surface.

Replacing the physical constants in equation (1) by their numerical values, taking the density of water = 1 $(g\ cm^{-3})$, equation (1) become:

$$E = \frac{29.9\ u^*\ (e_o - e_z)\ 10^{-5} N}{P\left(\ln \frac{z + 0.6}{d + 0.6} + 7.2\right)} \qquad \ldots\ldots\ldots\ldots (2)$$

where E is the evaporation (cm) and N is the number of seconds in the concerned month.

RESULTS AND ANALYSIS

Surface temperature and meteorological observations were averaged over a month and were then used to estimate evaporation. The reliability of the collected meteorological parameters were examined by comparing their monthly mean values to those averaged over longer periods. The used meteorological elements showed no significant discrepencies from the long term averages (Behairy, et al., 1981 a, b).

The annual evaporation from coastal waters (Table 1) was 205 cm with its maximum in May (22.8 cm) and minimum in September/October (12.0 cm). Evaporation from water along the Eastern Coast of the Red Sea had not been estimated before. Vercelli (1925) used pan observations to measure evaporation at Port Sudan and Suakin on the West Coast of the Central Part of the Red Sea. Although the two stations lie close to each other, evaporation at Port Sudan was 336 cm/year compared to 250 cm/year at Suakin. Maximum and minimum evaporation values were observed in July and February at both stations. Vercelli's evaporation values are much higher than the values reported here because it is well known that pans give too high evaporation values.

For open sea water (Table 1), the annual evaporation was 144 cm and had its highest value in November (17.0 cm) and lowest in September (9.6 cm). Evaporation reported here is much less than those estimated by Yegorov (1950), Neumann (1952) at latitudes 15°N and 25°N and by Privett (1959) at latitudes 25°N. Their values varied from 204 cm/year to 234 cm/year.

Comparison of annual evaporation from coastal water with that from open water shows that the latter constitutes only 70% of the former (Table 1). Month to month fluctuations in values of coastal evaporation were more significant than those of open water. Table 1 shows that monthly evaporation values from coastal water E_c are greater than those from open water E_s during most of the year. The greatest difference occured during spring when E_s was only 54% of E_c while in summer and winter E_s/E_c was 69%. In autumn, however, the two evaporation values were almost of equal magnitude.

The difference between evaporation values from coastal and open waters can be explained by examining all the parameters of equation (2) that influence evaporation. Table 1 indicates that the atmospheric pressure over coastal and open waters has very close values during the investigation period. Consequently, it has a negligable effect on the existing difference between coastal and open waters evaporation. Similarly, the effect of the height of observation z was negligable since the two sets of measurements were taken at almost the same height. The only remaining factors that may cause the observed difference between coastal and open sea evaporation are the vapour pressure deficit $(e_0 - e_z)$ and the friction velocity u^*.

Figure 3 shows that the vapour pressure deficit $(e_0 - e_z)$ over the coast is greater than that over the open water. Its value over the open sea ranges from 38% of that over the coast in spring to 63% in autumn. This reflects the relative dryness of the air over coastal water in comparison to that over open water specially in spring and summer. Consequently, if $(e_0 - e_z)$ was the only factor affecting evaporation we would expect higher evaporation from coastal water than from open water. Evaporation from open sea water represents only a fraction of that from the coastal water which ranges from 45% in spring to 100% in autumn. This indicates that, although $(e_0 - e_z)$ has a profound effect on the existing difference between coastal and open water evaporation, but it is not the only factor.

The friction velocity over the coast u^*_c was higher than that over the open water u^*_s. The ratio u^*_c/u^*_s varied from 50% in summer to 85% in winter (excluding January when it was 117%). It should be mentioned that coastal winds which were alternating daily between noctural land breeze and daytime sea breeze were the approximate vector summation of the broad scale flow and the duirnal component. On the other hand, over the open water winds were mainly directed along the central axis of the Red Sea with minor lateral variations (Behariy, et al., 1981 b). If the effect of the friction velocity was dominant, evaporation from the coastal water would be less than that from open water. Since this is not the case, it can be concluded that the friction velocity alone is not a major factor in determining the difference between coastal and open water evaporation. However, it is clear from table 1 that the ratios $E / \frac{(e_o - e_z)\ u^*N}{P}$ for coastal and open waters have very close values during all months. This means that for a given month the ratio E_s/E_c is almost identical to the ratio $\frac{(e_o - e_z)_s\ /\ (e_o - e_z)_c}{u^*_c\ /\ u^*_s}$.

Consequently, the difference in monthly evaporation from coastal and open waters can be explained by studying the monthly variations of these ratios. Thus, during the period from October through December, the ratio E_s/E_c approached 1 when $\frac{(e_o - e_z)_s\ /\ (e_o - e_z)_c}{u^*_c\ /\ u^*_s}$ was very close to 1. When the nominator of the last ratio was smaller than its denominator, E_s was less than E_c. This occured during the period from February to September inclusively. The maximum difference between E_s and E_c occured in May when $(e_o - e_z)_s\ /\ (e_o - e_z)_c$ attained its minimum value while u^*_c/u^*_s reached a maximum.

As mentioned before our data indicated that the quantity $E / \frac{(e_o - e_z)\ u^*\ N}{P}$ was almost constant during all months (Table 1). This quantity is equal to the factor $10^{-5} \times 29.9/(\ln \frac{z + 0.6}{d + 0.6} + 7.2)$ in Sverdrup's (1937) formula (eq. 2). The average value of this factor is 1.96×10^{-5} with a standard deviation of $\pm\ 0.03 \times 10^{-5}$ (using 24 readings). Substituting the value of this factor in equation (2) we get the following more simple form:

$$E' = 1.96 \times 10^{-5}\ \frac{N}{P}\ (e_o - e_z)\ u^* \qquad \ldots\ldots\ldots\ (3)$$

Equation (3) was used to recalculate monthly evaporation from the areas of investigation using the same observations. The results are given in Table 1 and represented graphically in Fig. 3. It is evident that the values of evaporation obtained from equations (2) and (3) are in excellant agreement. The average monthly difference was less than 1% except in February when it reached 7% for open water only.

The reliability of equation (3) was tested by using of observation collected from different climatic zones. Part of these observations were collected from regions of the Atlantic Ocean between latitudes 50°N and 55°S and was originally used by Sverdrup's (1937) to test his equation against Wust's observations. Table 2 shows that daily evaporation values obtained by equation (3) are in close agreement with those of Sverdrup. The average difference was 3.3% with standard deviation of ± 2.3%. The other part of observations was taken in Lake Qarun, Egypt (latitude 29° 30'N) (Meshal, 1973). Monthly evaporation from the lake estimated by Sverdrup's (1937) equation and by equation (3) are very close with an average difference of 5.9% ± 0.7% (Standard deviation).

TABLE 1

Monthly values of the parameters used in estimating evaporation from coastal and open sea waters in the Central Zone of the Red Sea.

Month	P_c (mb)	$(e_o-e_z)_c$ (mb)	u^*_c (cm/s)	E_c (cm)	$E_c'/\frac{(e_o-e_z)_c u^*_c N}{P_c}$	E'_c (cm)	P_s (mb)	$(e_o-e_z)_s$ (mb)	u^*_s (cm/s)	E_s (cm)	$E_s'/\frac{(e_o-e_z)_s u^*_s N}{P_s}$	E'_s (cm)
January	1014.5	15.23	25.75	20.2	$1.95.10^{-5}$	20.3	1013.8	8.97	21.94	10.2	$1.96.10^{-5}$	10.2
February	1012.3	13.59	18.03	11.5	$1.96.10^{-5}$	11.5	1012.2	7.67	26.72	9.6	$1.83.10^{-5}$	10.3
March	1011.2	14.60	23.18	17.5	$1.95.10^{-5}$	17.6	1010.2	7.34	34.10	13.0	$1.96.10^{-5}$	12.9
April	1008.1	15.81	23.18	18.4	$1.95.10^{-5}$	18.5	1007.9	7.09	32.51	11.6	$1.96.10^{-5}$	11.6
May	1006.6	18.93	23.18	22.8	$1.95.10^{-5}$	22.9	1006.0	7.21	27.25	10.3	$1.97.10^{-5}$	10.2
June	1003.8	17.87	20.60	18.6	$1.96.10^{-5}$	18.6	1002.7	7.40	26.27	9.9	$1.97.10^{-5}$	9.8
July	1002.9	24.13	12.88	16.4	$1.98.10^{-5}$	16.2	1001.7	9.99	21.75	11.4	$1.96.10^{-5}$	11.4
August	1003.5	23.19	18.03	21.9	$1.96.10^{-5}$	21.9	1002.7	9.42	25.32	12.5	$1.96.10^{-5}$	12.5
September	1003.7	15.33	15.45	12.0	$1.96.10^{-5}$	12.0	1005.0	7.22	26.24	9.6	$1.97.10^{-5}$	9.5
October	1009.2	17.70	12.88	12.0	$1.98.10^{-5}$	11.9	1008.6	9.18	25.90	12.4	$1.97.10^{-5}$	12.3
November	1012.7	19.25	18.03	17.4	$1.96.10^{-5}$	17.4	1011.1	12.33	28.21	17.5	$1.96.10^{-5}$	17.5
December	1014.5	19.89	15.45	16.0	$1.97.10^{-5}$	15.9	1013.0	11.92	25.32	15.7	$1.97.10^{-5}$	15.6

NB: E and E′ are evaporation values estimated from equation (2) and (3) respectively, the subscripts c and s indicate coastal and open sea waters respectively.

TABLE 2

Comparison of evaporation values estimated by Sverdrup's equation (E) and equation 3 (E′) using data from: a) Atlantic Ocean and b) Lake Qarun, Egypt.

a) Atlantic Ocean

Region	$(e_0 - e_z)\,u^*$	E (mm/day)	E′ (mm/day)	Difference (%)
50°N - 40°N	128.4	2.3	2.2	4.3
40°N - 30°N	190.5	3.3	3.2	3.0
30°N - 8°N	306.4	5.2	5.2	0
8°N - 3°N	106.2	1.9	1.8	5.0
3°N - 20° S	240.9	4.1	4.1	0
20° S - 40° S	175.1	3.2	3.0	6.3
40° S - 55° S	123.7	2.2	2.1	4.5

b) Lake Qarun, Egypt

Month	$(e_0 - e_z)\,u^*$	E (cm)	E′ (cm)	Difference (%)
January	108.8	6.0	5.6	6.7
February	187.4	9.1	8.6	5.5
March	254.7	13.8	13.0	5.8
April	365.4	19.2	18.1	5.7
May	449.0	24.6	23.0	6.5
June	527.4	28.2	26.2	7.1
July	399.1	21.9	20.6	5.9
August	388.7	21.3	20.0	6.1
September	390.2	20.4	19.4	4.9
October	275.1	14.9	14.1	5.4
November	124.8	6.6	6.2	6.1
December	73.7	4.0	3.8	5.0

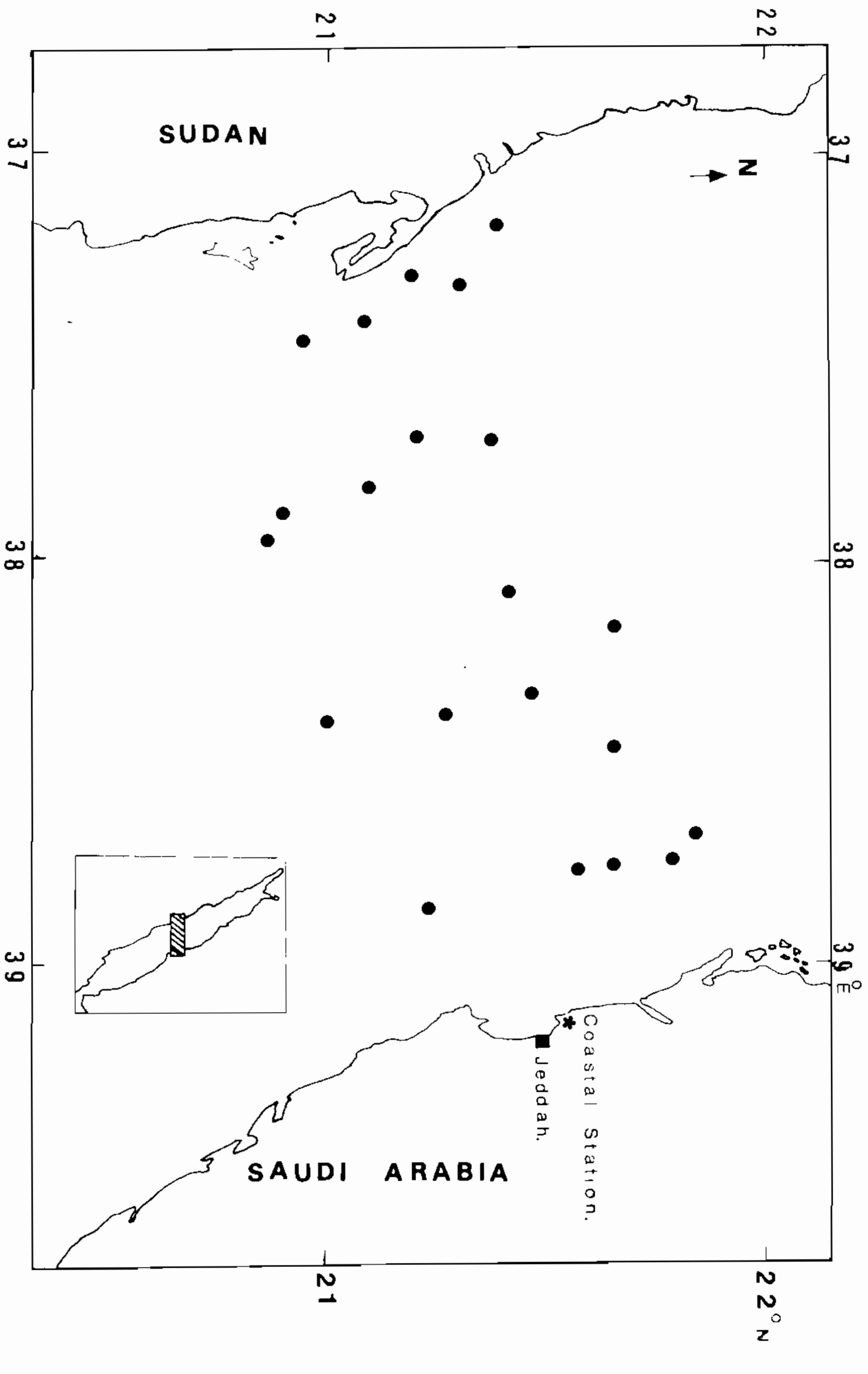

Fig. 1: The area of investigation, position of the coastal station, and location of hydrographic stations in the open water where data were collected.

ACKNOWLEDGEMENTS

Evaporation from the open water in the central part of the Red Sea calculated from observations collected during an environmental survey in the region of the hot brines. The survey was organized and funded by the Saudi Sudanese Commission for the Development of the Red Sea Resources.

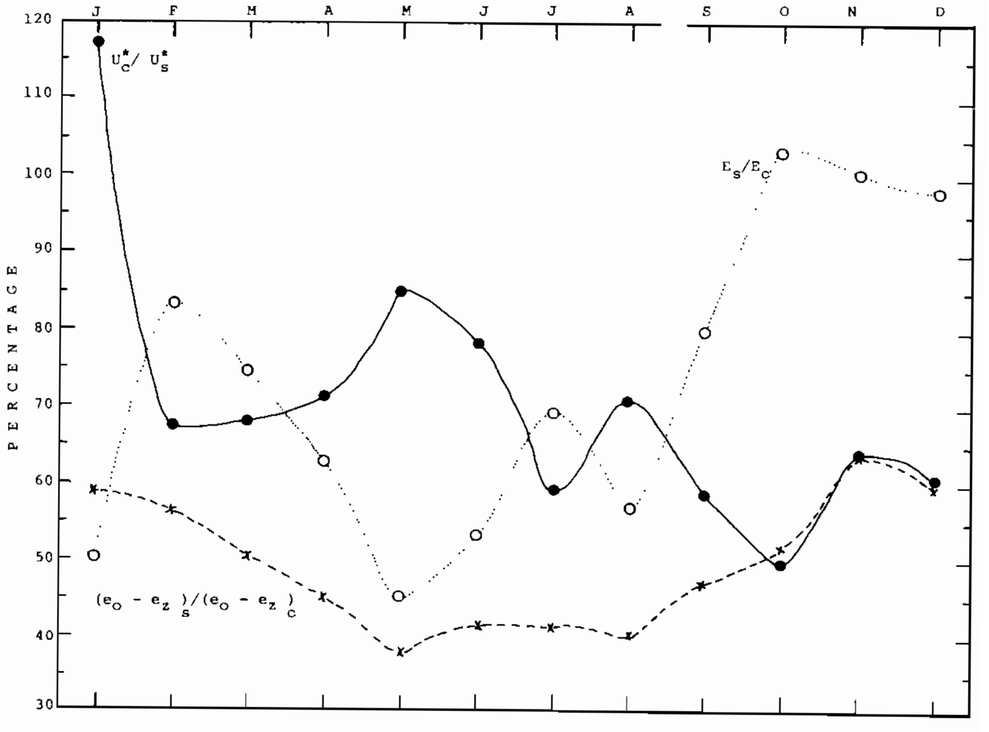

Fig. 2: Monthly variations of the ratios: $(e_o - e_z)_s / (e_o - e_z)_c$; u^*_c / u^*_s and E_s/E_c.

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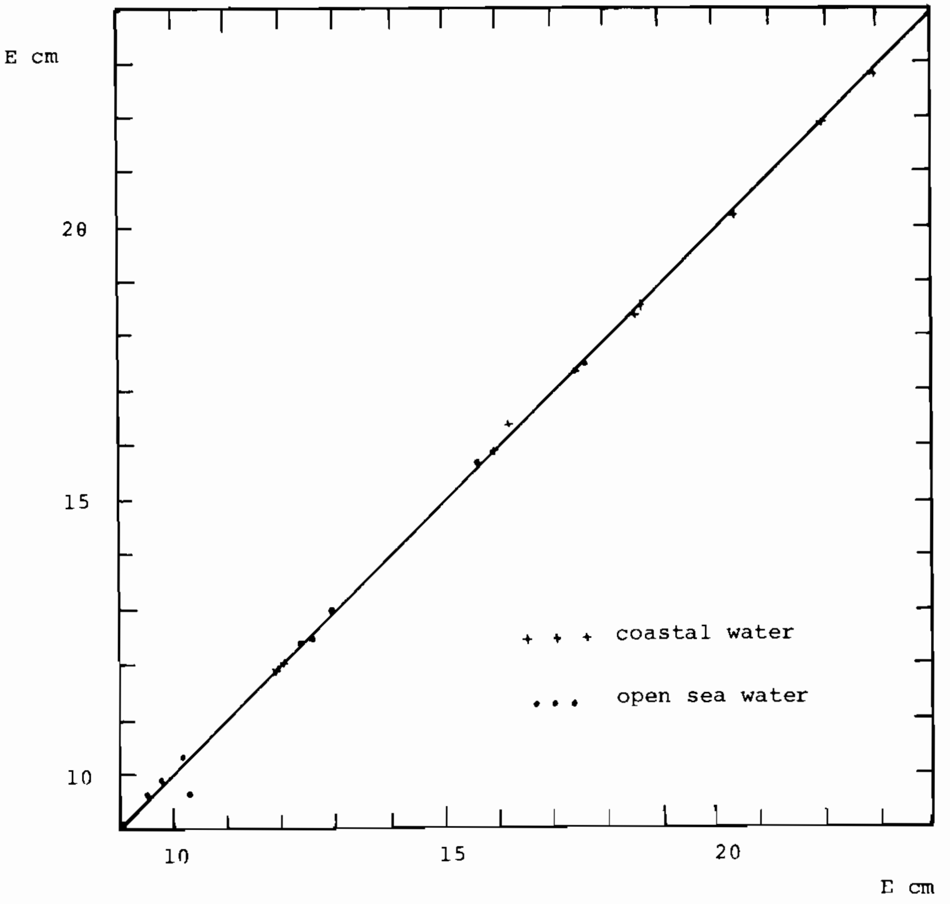

Fig. 3: Comparison between evaporation values E and E′ obtained from equation (2) and from equation (3) respectively.

مقارنة لمعدلات البخر من المياه الساحلية والطليقه للجزء الأوسط من البحر الأحمر

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حسبت القيم الشهرية للبخر من المياه الساحلية والطليقة للجزء الأوسط من البحر الأحمر فيما بين خطي عرض ٢١ و ٢٢ شمالا . ولقد استخدمت الطريقة الأيروديناميكية لتعيين البخر باستخدام مجموعتين من البيانات جمعت أولهما من محطة ساحلية تقع على الساحل الشرقي للبحر الأحمر والأخرى من البحر الطليق .

ولقد وجد أن كمية البخر السنوي من المياه الساحلية تعادل ٢٠٥ سم وتبلغ أقصى قيمة شهرية للبخر في مايو وأقلها في سبتمبر وأكتوبر أما بالنسبة لمياه البحر الطليق فلقد وجد أن معدل البخر السنوي هو ١٤٤ سم . ويبلغ أقصى قيمة له خلال شهر نوفمبر . وأقل قيمة خلال سبتمبر .

ولقد تبين أن قيمة البخر الشهرية لكل من المياه الساحلية والطليقه تتساوى خلال فصل الخريف في حين أنها واضحة التباين خلال فصل الربيع .

وبالنسبة للمنطقة الساحلية . فلقد وجد أن التأثير القاري كان واضحا على قيم ضغط بخار الماء وسرعة الرياح الاحتكاكية مما أثر على قيم البخر المحسوبة .

ولقد بينت الدراسة أن حاصل ضرب النقص في التشبع لبخار الماء والسرعة الاحتكاكية هو العامل الأساسي المحدد لقيم البخر . وان كل العناصر الأخرى التي تدخل في معادلة الحساب لها تأثير ضعيف يمكن اهماله .

ولقد أمكن استنباط معادله بسيطة لتعيين البخر اختبرت دقتها باستخدام بيانات جمعت من مناطق مناخية مختلفة . وبينت النتائج المتحصل عليها أن هذه المعادلة البسيطة تعطى قيم تتفق بصورة ممتازة مع تلك المحسوبة باستخدام المعادلة الأكثر تعقيدا .