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The water balance of the Caspian Sea and Aral Sea

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ABSTRACT The effect of water vapour, transferred from irrigated lands of the USSR Central Asia, on the evaporation from the Caspian Sea surface has been proved. The fresh water flowing to the Aral Sea was used for irrigation. The other processes influencing the moisture content of air masses over the Caspian Sea surface have been discussed as well. The possible changes in the Caspian Sea level fluctuations under the effect of changes in the moisture content over the sea surface by 12.5% and 6% have been determined.

Beginning from 1930 to 1975 the Caspian Sea level constantly droped from an elevation of -26.08 to -29.0 m. Since 1978 the sea level began to rise and this rise continues until present. The sea level rose by 1.2 m and reached an elevation of 27.8 m for the period under consideration. The water volume accumulated for these years amounted to about 450 cu km.

The Aral Sea level from 1860 to 1960 was relatively constant and amounted to 53 m. After 1960 a sharp decrease in the sea level began and at present it is approaching an elevation of 43 m, i.e. lowered by almost 10 m. The water volume of the Aral Sea decreased by about 450 cu km for the same period (Table 1).

The consideration of the sea water balances has shown that the increase in the Caspian Sea volume for the last 10 years (450 cu km) equals the decrease in the Aral Sea volume for 25 years. This coincidence seems to be of no accidental character and expresses a close relationship of the present level regimes of these seas.

The water balance equation for these drainless seas may be written as:

$$d/dt(Fh) = 1/\rho\,(FJ_{ev} - FJ_{pr} + Q) \qquad (1)$$

where F = water surface area; h = water level height; J ev and J pr = evaporation and precipitation related to unit area, respectively; ρ = water density.

Equation (1) for average annual characteristics is:

$$\bar{F}\,J_{ev} - \bar{F}\,J_{pr} - Q \pm \Delta W = 0 \qquad (2)$$

TABLE 1 Hydrological characteristics of the Caspian and Aral seas in 1930 (upper value) and in 1990 (lower value).

Level (a.el. in m)	Water surface area (th sq km)	Average depth (m)	Volume (cu km)
		Caspian Sea	
-26.03 / -27.80	404.2 / 380.2	200 / 200	78200 / 78000
		Aral Sea	
53.0 / 43.0	60 / 20	20 / 10	1020 / 570

where $\bar{F} = (F_1 + F_2)/2$; F1 and F2 = sea surface area earlier and later in the year; ΔW = sea water volume change; Q = river runoff.

For the Caspian Sea, the average annual characteristics for 57 years (from 1930 to 1986) have been obtained as follows:

$$F\,J_{ev} + \Delta hF = const. \quad (3)$$

If the water volume is expressed in cubic kilometres, then the constant in Equation (3) equals 368.7 cu km, and

$$F\,J_{pr} + Q = const. \quad (4)$$

It is natural that the constant in Equation (4) is also equal to 368.7 cu km.

For the Aral Sea, the change in the water volume was mainly due to the decrease in the water inflow to the Amudarya and Syrdarya that may be written as:

$$\Delta F = (\Delta Q / \Delta h)\, \Delta t \quad (5)$$

It follows from the computations that for the Aral Sea the following condition may be adopted:

$$\bar{F}\,J_{ev} \approx const \approx 54 \text{ cu km} \quad (6)$$

Consider processes governing the present water level regime of the Caspian and Aral seas and causing temporary changes in their volume: processes of the change in the radiation balance of the underlying surface of the region; characteristics of the moisture exchange between the Karakumy Desert and the Caspian Sea; increase in the area of irrigated lands in the USSR Central Asia; increase in the concentration of substances (largely sulphur compounds) in the atmosphere forming condensation nuclei; processes of the formation of the altitudinal moisture distribution and its relation to the distribution of the atmospheric energetic field and condensation nuclei; the effect of inversion and isothermals on the processes of moisture exchange between irrigated lands of the USSR Central Asia and the Caspian Sea.

The radiation balance R of the Earth's underlying surface is expressed by the total solar radiation Q, reflected solar radiation expressed by albedo A, and effective radiation E:

$$R = Q\,(1-A) - E \qquad (7)$$

The annual total R for the region under consideration, limited by 60° NL and 60°EL, amounts to 3600 MJ/sq m, while for the Kopetdag foothills the June R value alone equals 800 MJ/ sq m. For the last decades, the ratio of direct and diffuse radiation has changed appreciably. Over the USSR's European area, direct radiation decreased by 5%, while diffuse radiation increased by about 50% that is explained by the decrease in atmospheric transparency.

The radiation balance in the Caspian Sea and Aral Sea basins has drastically changed due to the increase in the moistened land area. In the USSR Central Asia, in summer, the radiation balance of irrigated lands is 60% larger than that of natural desert surfaces. This is explained by the fact that the albedo of moist soil and green plants is smaller as compared to that of desert, and the effective radiation in oases is weakened due to the lower temperature of the surface, larger air moisture content, and emerging long-wave temperature inversions.

Thus, large-scale irrigation in the region under discussion resulted in an increase in the integral values of the radiation balance of the growing season and in the transfer of its energy into the atmosphere in the form of latent heat. This is due to the fact that the radiation balance depends on the ratios of its energy expenditure for total evaporation and turbulent heat exchange between the soil surface and the atmosphere, and on the heat flow into the soil:

$$R = LE + P + B \qquad (8)$$

where LE = heat flow related to phase transformations, i.e. evaporation and condensation; P = turbulent heat flow between the Earth and the atmosphere; B = heat flow spent for soil heating and cooling.

Owing to small values and the change in the sign during the year $B \approx 0$, therefore the main role in the output portion of the heat balance is played by LE and P.

The relative quantity of heat transferred in the direct form (P) and latent form (LE) depends mainly on land moisture content. Prior to 1960, the average radiation balance was:

$$R = LE + P = 9.6+14.6 = 24.2 \text{ MJ/sq m/yr} \quad (9)$$

and in 1985 it was:

$$R = 16.8+14.6 = 31.5 \text{ MJ/sq m/yr} \quad (10)$$

Thus, in the region under discussion, the heat balance sharply changed at the expense of heat flow related to evaporation. At a given value of R the components LE and P are the main regulators of the heat regime between sea surface and adjoining air layers. If P is the heat flow between the surface and air that influences the process of evaporation directly in the heat exchange region, then LE is the heat flow that entering the atmosphere in the latent form together with water vapour is transferred over long distances and thus influences the processes of evaporation and condensation of water vapour. The physiographic conditions in this region are such that the heat flow is directed to the Caspian Sea.

The characteristics of heat and moisture exchange between the Karakumy Desert and the Caspian Seas are as follows.

The transfer of heat from west to east predominates over the USSR area. In the USSR southern regions, easterly winds predominate, their great recurrence is observed over South Kazakhstan and USSR Central Asia. In southern USSR Central Asia, northwestern winds blow for 40-50% of the time within a year. In the lower layers of the atmosphere, however, even with west winds, easterly winds predominate, i.e. they blow in the direction of the Caspian Sea (Kuznetsova, 1983).

Attention should be given to the large moisture content in the middle layers of the atmosphere in this region. At the Moscow latitude, the specific moisture content amounts to 5 g/kg, while over USSR Central Asia area it is 10 g/kg. The irrigated lands whose moisture enters the atmosphere lie in a passage that connects them with the Caspian Sea, and thus processes of heat and moisture exchange are effected in regions adjoining the Caspian and Aral seas. This system has distinct geographical boundaries. The Aral Sea is located in the north, the Syrdarya flows along the south-north boundary, and the Caspian Sea borders in the west. The Karakumy Desert lies in the centre of this system (its height is up to 355 m) and it leans against the Ustyurt Plateau. The Zaunguz Karakumy Desert is located from west to east, its elevation is 240 m above sea level. The Central Karakumy Desert with absolute elevations of about 50 m lies between the high scarps of Unguz, the Kopetdag Range and Maly Balkhan. These structures form the passage from north to south to the Caspian Sea. The Karakumy Canal is located in the southern portion of this passage close to the Kopetdag Range. The moisture evaporated from irrigated lands adjoining the Karakumy Canal is transferred by the east-west prevailing winds to the Caspian Sea and covers it with a moist counterpane thus reducing evaporation from it.

The moisture content in the Krasnovodsk area in 1960 was 16.6 g/kg, in 1975 17.4 g/kg, in 1978 21.8 g/kg, but in 1985 it decreased to 19.0 g/kg.

For the last 25 years the moisture content increased by about 20% and its maximum rise was observed in the middle 70s when the Caspian Sea level rose. A similar increase in moisture content was observed in the area of cities of Chardzhou and Ashkhabad. Thus, the moisture content in the atmosphere increased everywhere along the line connecting the movement of air masses in the direction of the Caspian Sea. This was due to irrigation development in USSR Central Asia.

The area of irrigated lands in USSR Central Asia was expanded at the expense of the water resources of the Aral Sea basin: 120 cu km/yr of water was used including 40 cu km/yr from the Syrdarya basin and 80 cu km/yr from the Amudarya basin.

These water amounts characterize the water availability in the river basins as a whole, including areas (the Zeravshan, Kashkadarya and other river basins) whose runoff is completely consumed and lost at the present stage of irrigation development, not reaching the main stems of rivers feeding the sea. The total appraisal of the water resources of the basin, including the runoff of its portions practically remote from the Aral Sea, is of interest because it is impossible always to class irrigated lands by their water source. For instance, lands adjoining the Karakumy Canal obtain water also from the Murgab and Tedzhen rivers; water from the Amudarya is delivered through the Amu-Bukhara Canal to the Zeravshan basin. By 1970, of 120 cu km/yr of water flowing from the basins, only 47 cu km/yr, i.e. less than half, reached the sea. The rest of the water was taken for irrigation and then it evaporated, or evaporated from reservoirs and lowlands adjoining the rivers. In 1982, no drop of the Amudarya water reached the Aral Sea.

The groundwater contribution to the water balance of the Aral Sea amounts to about 1 cu km and therefore it may be not taken into consideration.

The area adjoining the rivers feeding the sea and economically connected with them exceeds the area of the Caspian and Aral seas almost 4 times.

The irrigated land area in the region under discussion amounted to 4,900,000 ha in 1940 and 8,000,000 ha in 1985. In the Aral Sea basin, irrigation of cotton is preferred. The area of irrigated lands sown to cotton accounts for 60% of all the irrigated lands. About 10,000,000 tons of cotton is produced annually here.

In addition to irrigation, pasture watering for livestock breeding is of great importance. Under present conditions, an area of 40,000,000 ha, almost equalling the area of the Caspian and Aral seas has been watered.

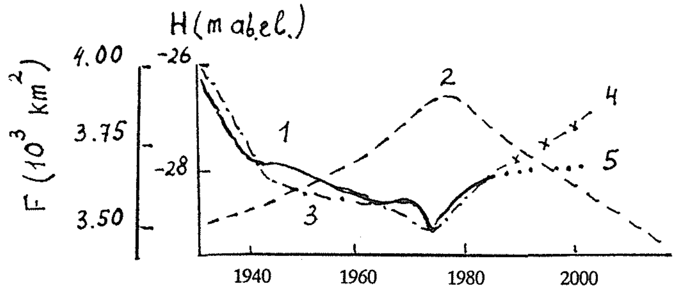

FIG. 1 Fluctuations of the Caspian Sea level (1) and evaporation from its surface (2), the actual (3) and predicted change in its area at an increase in moisture content by 12.5% (4) and 6% (5).

The area with total evaporation in the summer-autumn period amounts to about 50,000,000 ha that is larger than the Caspian Sea area.

The total evaporation in this region accounts for about 70% of the moisture evaporating from the Caspian Sea. This effect naturally decreased the evaporation from the Caspian Sea thus contributing to its level rise since 1977.

Besides, the sea level regime has been also affected by the global pollution of the atmosphere with substances forming condensation nuclei (Petrenchuk, 1979).

Figure 1 shows the change in the Caspian Sea area and its prediction based on the excess of the 1975 moisture content by 12.6 and 6%, respectively. In the first case, the Caspian Sea area will increase and will be equal to 405,000 sq km, i.e. the Caspian Sea level in 2000-2010 may rise by another 1.8 m. The prediction presented in Fig. 1 takes into consideration only the change in moisture content in the atmosphere caused by irrigation development in USSR Central Asia, other conditions being invariable.

It is natural that with changes in the input portion of the Caspian Sea water balance (river runoff and precipitation onto the sea surface) the predicted sea level values also change that follows from balance equations (1) and (2). It is essential that the other processes influencing the output portion of the water balance (evaporation from the sea level) are also taken into consideration.

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