Changes in the Aral Sea level and the Run-off of Main Rivers in Central Asia for Last 20,000 Years

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Abstract Modern degradation of the Aral Sea is due to intensive depletion of water from rivers Amudarja and Syrdarja, feeding the Sea, for agriculture. However, the Sea had significant changes in the past, connected with climate changes. All components of its water balance have changed: inflow by the rivers, evaporation from water surface and precipitation on it. From time to time outflow of water from the Aral Sea basin to the Caspian depression by the Uzboj Channel has occurred. A large volume of data on climate change and hydrological situation in Aral Sea region in the Pleistocene and the Holocene has been collected up to the present. A method of linking up these numerous data was proposed. As a result integrated data on changes of climatic and hydrologic conditions at Aral seaside has been got for former approximately 20, 000 years. The reliability of results decreases with penetrating deep into centuries.

Key words: Central Asia, Aral Sea, water balance, river run-off, paleoclimate

1. Introduction

Modern degradation of the Aral Sea is due to intensive depletion of water for agriculture from the rivers Amudarja and Syrdarja, feeding the Sea. However, the sea had significant changes in the past connected with climate change. All components of its water balance have changed: inflow by the rivers, evaporation from the water surfaces and precipitation. During several phases the outflow of water from the Aral Sea Basin to the Caspian Depression by the Uzboj Channel has occurred (Bortnik and Chistjakova, 1990).

A large volume of data on climate change in the Aral Sea Region in the Pleistocene and the Holocene was collected at present (Abramova, 1989; Vinogradov and Mamedov, 1974; etc.). Long-term investigations of former channels of the Syrdarja and Amudarja Rivers and ancient shorelines of the Sea supplied by extensive archeo-

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logical data have allowed to calculate run-off of the largest rivers of Central Asia, and the level and surface area of the Sea for some intervals of time.

2. Reconstruction of past run-off and sea-level change

Past run-off was evaluated using data on ancient bed's parameters of the rivers Amudarja, Zeravshan, Syrdarja and the Uzboy Channel. Shape and areas of cross sections, bed inclination, meanders geometry were measured.

Time when water flew in the channels was found on multiple archeological, geological and geomorphologic data. Radiocarbon method was used for several ancient beds of the Zeravshan River (Vinogradov *at al.*, 1977). It was found that past run-off was as much as 3-4 times more than present day one. Water inflow to the Aral Sea by the rivers was equal to 90-130 km^3/year (Trofimov, 1986).

Marine traces of seven former levels of the Sea were found (Vainbergs and Stelle, 1980). These are terraces on (a) absolute height 72-73 m, (b) "Old Aralic" terrace (height 57-58 m), (c) "Late Aralic" terrace (height 54-55 m), (d) terrace, corresponding to the maximum level of modern stage (1911-1961) (height 53 m), and coastlines on heights (e) 43.0-44.5 m, (f) 40.0-41.0 m, and (g) 35.5-36.0 m. Besides, the Sea bottom sediments taken in Paskevich Bay and Tshche-Bas Bay at approximate height 31 m permit to separate so named "Paskevich" stage of the Sea development. In the opinion of these authors, it was the stage of long-term Sea regression. It seems that three following, more high marine terraces were due to stages of stabilization of the Sea level during its ascent after "Paskevich" stage.

Khondkarian (1977) has described a marine terrace on level 63-64 m, which was only partly seen and vastly ruined. It may be referred to "Old Aralic" stage of the Sea developments as well.

Practically all researchers noted a stage of regression of the Sea before "New Aralic" one. There is divergence of opinions in the regression size and time (Maev and Maeva, 1983). Principal levels of transgression and regression of the Sea are shown in Fig. 1.

"Paskevich" stage sediment formation covered Late Pleistocene and early Holocene series (Vainbergs and Stelle, 1980). The authors took into consideration mainly palynological data and general view to vegetation change during that time, as significant scatter of absolute dates was found for salts from the sediments.

An upper chronological border of that stage, indicated by Vainbergs and Stelle (1980), was defined more accurately using results of archeological studies (Vinogradov *at al.*, 1977 ; etc.).

Any expressive Mesolithic materials (with some exclusion of the final Mesolithic stage) are absent in the region. On the contrary, there are many archeological

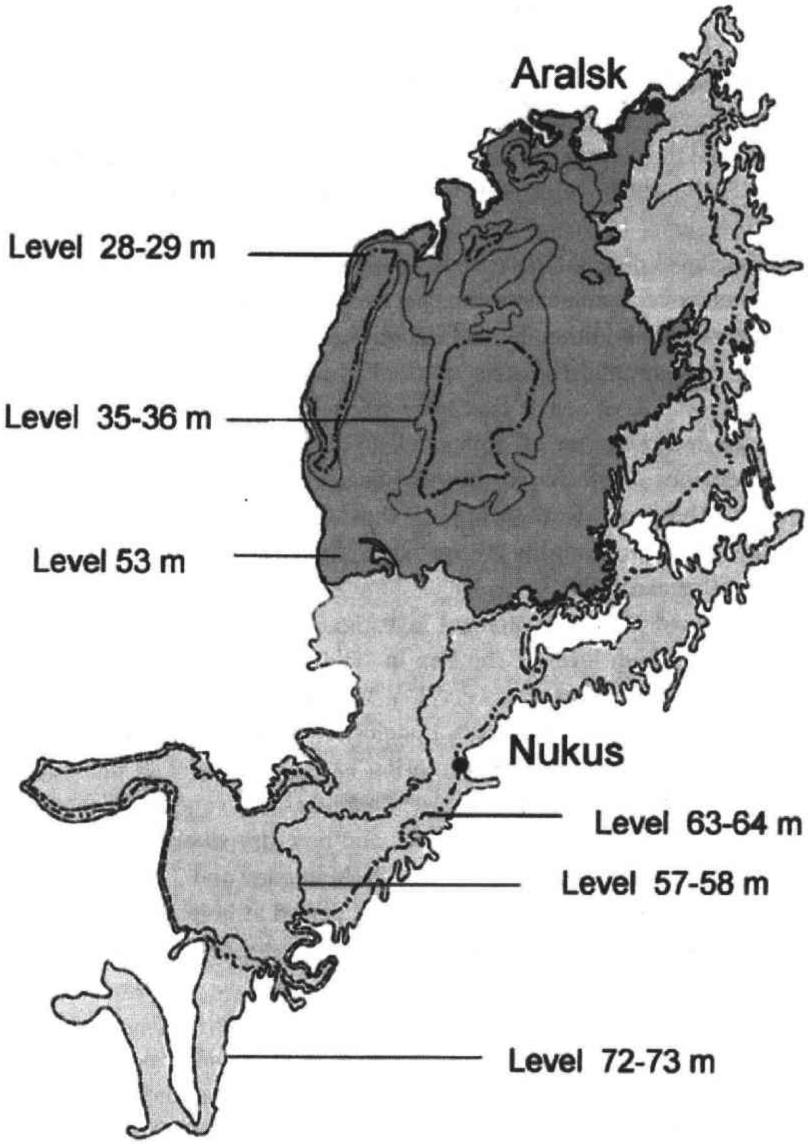

Fig. 1 Stages of the Aral Sea development in Late Pleistocene and Holocene

evidences of Neolithic time. That is why shift from unfavorable climatic and hydrological conditions ("Paskevich" stage) for habitant existence to humid and warm climate ("Ljavljakan pluvial" stage) can be dated by VII-VI (or VIII-VII) millennia BC.

A problem of area and level of the Sea in "Paskevich" stage was weakly solved by Vainbergs and Stelle (1980). It was mentioned only that it was characterized by very low level. The Aral Sea has been disintegrated into two independent pools at least: the Small Sea and the part occupying the rest of its depression.

In our opinion, it is more correct to consider a coastline on absolute height 35.5-36.0 m as one of the lowest quasisteady Sea levels during "Paskevich" stage. Vainbergs and Stelle (1980) referred it to "Taranglyk" stage of the Aral Sea development.

The low Sea level during "Paskevich" stage can be interpreted by different way. According to a paleogeographical scheme by Kes' (1979), the Amudarja River flew to Sarykamysh depression and then by the Uzboj Channel to the Caspian Sea during the end of Late Pleistocene and the most part of Holocene. Only the Syrdarja River carried water into the Aral Sea at that time. Surely climatic situation played a role in water balance and river run-off was small (Velichko and Lebedeva, 1974; etc.).

A point of serious discussion in the Aral Sea problem is possible time of ancient transgression of the Sea. Correlation of the "Old Aralic" marine terrace with Neolithic archeological material is a direct indication to its age. The upper limit of this age is III millenniums BC.

Archeological and paleogeographical investigations of two last decades allow to date highly definitely high level of the Sea in "Old Aralic" stage. It was a time of rising of run-off by Uzboj Channel, i.e. VI-V millenniums BC. Thereby, this stage existed 8-5 thousand years ago. This conclusion corresponds to the opinion of Khondkarian (1977). Its indirect confirmation is coincidence of "Old Aralic" transgression with a period of warm, comparatively humid climate and significant river run-off. All old channels of the Amudarja River and now dry riverbeds of the Syrdarja River (Kuvandarja and Inkardarja) had run-off (Mamedov and Trofimov, 1986; etc.).

Level of Sea existed for comparatively short period at height 72 m. It decreased to height 63-64 m and then to 57-58 m as a result of water outflow origination by the Uzboj Channel.

3. Water balance of the ancient Aral Sea

The problem was to link up these numerous data for evaluation of principal components of water balance of the Sea under various former climatic conditions. It was necessary, on the one hand, for cross check of accumulated data, and on the other hand, for filling up gaps in them.

An equation of the annual water balance of the Sea should look as follows, would principal components be included only:

$$\frac{dh}{dt} \cdot F(h) = Qr + Qu + (X - E) \cdot F - Qo,$$

where h is water level in the Sea ; F is its area when the level equals h ; t is time ; Qr and Qu are annual surface and underground inflow to the Sea ; X and E are annual layers of precipitation and evaporation on the Sea surface ; Qo is outflow of water by the Uzboj Channel.

Periods when large marine terraces were formed were considered and it was possible to admit that the level of the Sea was about constant at that time, so $dh/dt = 0$.

Shifts of annual (or seasonal) precipitation and annual (or seasonal) mean air temperature are usually considered to be the characteristics of climate change (Abramova, 1989 ; etc.). Therefore, it was necessary to find the dependencies of the seawater balance components on these parameters. Data from meteorological station Tamdy, well reflecting the integrated meteorological conditions of the region, and data on modern fluctuations of water balance components of the Sea (Hydrometeorology, 1990) were used for the calculations. Evaporation E and precipitation X were evaluated for periods with known climate parameters, using the found dependencies.

Precipitation during Early-Middle Holocene were evaluated using its relationship with past run-off of the Sazagansaj (a left tributary of the Zeravshan River) (Mamedov and Trofimov, 1992).

Water inflow Qr was evaluated using either characteristics of ancient channels or dependencies of run-off on precipitation and glaciation area of mountains in the Aral Sea watershed (Glazirin *et al*., 1989). The outflow by the Uzboj Channel was determined using morphometric characteristics of the Channel for periods when run-off has occurred (Trofimov, 1986 ; etc.).

Underground inflow to the Sea was accepted as a constant and equal to 1 km^3/year (Hydrometeorology, 1990).

Then a technique, which permitted calculation of air temperature change at given changes of precipitation, was developed. It was possible to solve the opposite problem too—calculation of precipitation change required for the water balance maintenance under a given change of air temperature. As a result, it was possible to evaluate integrated data on changes of climatic and hydrologic conditions at the Aral seaside for about the last 20,000 years (Table 1).

It is necessary to note that it was not possible to do the evaluation for some periods. Surely, reliability of results decreases with penetrating deep into centuries.

4. Ancient irrigation and its influence on water balance of the Aral Sea

In the opinion of Shnitnikov (1983), there exist a significant number of historic sources which indicate deep regressions of the Aral Sea in IV–V centuries AD.

Table 1 Long-term changes of climate, run-off of main rivers of Central Asia and Aral Sea level during the last 20000 years

Time	Level of Aral Sea	Change of air temperature	Change of annual precipitation	Run-off of the rivers	Outflow by Uzboj Channel
	m	℃	%	km³/year	km³/year
Centuries AD					
Present day	53.0	0	0	56.9	0
XVI-XIX	52.0	-	-	-	-
XV	53.1	−2.5	30	58−59	7−8
XIII-XIV	53.7	−2.2	30	60−62	10
XII	53.1	−0.5	20	63−64	7−8
XI	50.0	−0.5	−10	49−50	0
IX-X	-	-	-	-	-
VIII	51.8	−3.6	80	44−45	0
V-VII	52.0	−0.5	20	52−53	0
I-IV	28.5	-	-	-	-
Thousands of years BP					
2-2.5	54.5	-	-	-	27
2.5-3.5	-	-	-	-	-
3.5-4.0	54.5	−2.0-−2.1	40-50	82-83	27
4-5	57-58	−3.6-−3.7	60-100	118-126	63-66
5-7	63-64	−3.6-−3.7	80-100	127-131	67-72
7-9	72-73	−3.6-−3.7	60-100	91-92	0
9-10	43.7-44.5	−4.5-−5.0	−40-−50	33-34	0
10-12	40-41	−12.5-−13	−70-−60	13-14	0
12-20	35.5-36	−13.5-−14	−80-−70	9-10	0

Desertification of ancient irrigated lands took place during that time in the region (Kes', 1979).

Andrianov (1969) thinks that traces of agriculture in Central Asia can be referred to IV-V millenniums before BC. Firth and brook type irrigation was developed at that time. Beds of dried rivers were used as well (Lisitzina, 1965). It is difficult to evaluate area of simultaneous former irrigation. However, this area was located at riverbanks and could not be large enough. Accordingly, few loss of water took place. Nevertheless, archeologists evaluated that the total area (for various time) of ancient irrigation in Central Asia was equal to 3.5-5.0 million hectares (Tolstov, 1948).

5. Past climates

Climatic situation in Central Asia had significant changes for the last 20 millenniums. Precipitation and air temperature changed. As a result, evaporation from the Sea surface and run-off of rivers changed as well. It is interesting to note that for this long-period mean annual air temperature was always less than modern one.

Our evaluations of air temperature for the last two millennia are practically the same as the results of Abramova (1989). In our opinion changes of precipitation were less than she found.

Most changes of the climate features were found for the end of Late Pleistocene when air temperature was as much as 10-14°C lower than modern one.

Velichko (1977) studied climate of periglacial area of Eastern Europe for 15-23 thousand years BP in detail. He found that the duration of annual period without frost equals 80-100 days in latitudes between 50-55° North. Annual precipitation was approximately 100 mm. Air temperature in January was −30−−34°C. However air temperature in July was below modern one by 3-4°C only. Permafrost reached 42° North. Mean annual air temperature did not rise above −5.5°C on this latitude.

It was much colder in Early-Middle Holocene as well. Under these thermal conditions and precipitation which was 1.5-2 times more than modern one, mountain glaciation area in the Sea watershed increased and river run-off was 3-4 times more than modern one. Evaporation from the Aral Sea was less. These reasons stipulated stages of transgression and very high water level. In turn, it has entailed water outflow by the Uzboj Channel to the Caspian depression.

6. Conclusion

We think that more reliable data on former climate and run-off of main rivers in Central Asia were found. Regrettably, it was not possible to calculate the climate parameters and the water balance components for some stages of the Aral Sea development in the Pleistocene and the Holocene. For instance, it is not clear what climatic situation corresponded to very deep regression of the Sea in the first century AD. Climatic situation was comparatively close to modern one. Nevertheless the water level was very low and the Sea was divided into several separate pools. If so, we have an analogue of present day condition of the Aral Sea in the past.

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