Investigation of Hydrological Change in Closed Lake of Arid and Semi-Arid Regions

Yasunori Nakayama(*), Sotaro Tanaka(*), Toshiro Sugimura(*),
Kunihiko Endo(**) and Yuzou Suga(***)

*Remote Sensing Technology Center of Japan
1-9-9 Roppongi, Minato-ku, Tokyo 106 Japan
Fax:+81-3-5561-9542
Email:nakayama@restec.or.jp, tanaka@restec.or.jp,
sugimura@restec.or.jp
**Department of Earth Science, Nihon University
3-25-40 Sakurajosui, Setagaya-ku, Tokyo 156 Japan
Fax:+81-3-3290-5451
Email:endo@chs.nihon-u.ac.jp
***Hiroshima Institute of Technology
2-1-1 Miyake, Saeki-ku, Hiroshima 731-51 Japan
Fax:+81-829-22-5204
Email:ysuga@ds5.cc.it-hiroshima.ac.jp

Abstract

This paper describes a method for the investigation of hydroogical change in closed lake by using satellite data, bathymetric map, and meteorological observation data. The changes for the last about 30 years in water balance of Aral Sea and Lake Balkhash were analyzed in detail. The effect of human activities in the change of Aral Sea, and both effects of human activities and natural climate variation in the change of Lake Balkhash were presumed.

1. Introduction

The water area in closed lakes which are locating in arid land of the Asian and African continents are changing by the influence of the environmental change within their drainage area. Especially, most of these lakes have been rapidly changed for the last about 30 years. Authors showed that the human activities and the climate variation along the inflow river had the effect on the remarkable change of the water area in lakes based on the results of the investigation for change situation using satellite data (Nakayama *et al.* 1994, 1995, 1996). However, the precise examination for the effect of human activities or natural variation to the change of closed lake and its drainage area is necessary to analyze satellite data with ground survey data in detail.

In this paper, the remarkable change in the water volume for Aral Sea and Lake Balkhash of central Asia was firstly described by the analysis of multi-temporal satellite data with the

bathymetric map, and next, the hydrological change was reported on comparing these results with the variation of meteorological observation data.

2. Analysis method

2.1 Water balance of closed lake

Our previous investigation using satellite data showed that the water area with about $66x10^3km^2$ of Aral Sea and the one with about $18x10^3km^2$ of Lake Balkhash at 1960 had shrunk to about 67% and 89% respectively for about 30 years afterwards. On the other hand, the decrease in inflow volume caused by the consumption of river water was grasped because the irrigation field along inflow river enlarged (Nakayama *et al.* 1994).

The change of lake have been generally described by means of the variation in water level in the previous study. However, the more detailed investigation at the viewpoint of water balance is possible by analyzing the relationship among the changes of water volume, inflow/outflow and evaporation in lake.

The water balance in closed lake is described as follows;

$$\Delta QL=PL-EL+R+GL \qquad (1)$$

where ΔQL is change volume of lake water, R is inflow volume from the surface, PL and EL are the calculated precipitation and the estimated evaporation in water area using meteorological observation data respectively, and GL is inflow/outflow volume of underground water. Water volume QL is calculated by water area A from analyzed satellite data and bathymetric map based on ground survey. Then, $\Delta QL(=QL_1-QL_2)$ is given by the changed water volume of lake for the period of object years. PL and EL are estimated as

$$PL=A \times P \qquad (2)$$

$$EL=A \times E \qquad (3)$$

where E is estimated by using P and A. GL of equation(1) is difficult to observe in actuality. In this analysis, we defined the changes of precipitation, evaporation and inflow volume of surface only affected the change of water volume on the assumption that GL was unchangeable.

2.2 Data and analysis procedure

The analyzed results for the changes in water area of lake and vegetation area along inflow rivers from satellite data and other sources had been reported (Nakayama *et al.* 1994, 1995, 1996). This paper described the estimation of changes in water volume and water level, and

analysis of water balance in lakes by using the images detected water area change from satellite data and bathymetric map. The flow of this analysis is shown in figure 1.

A bathymetric map of Aral Sea produced by the former USSR and a corrected bathymetric map of Lake Balkhash based on the utilized document (Kurata *et al.* 1994) were used. The isobathymetric lines from each map were converted to digital isobathymetric images with 250m x 250m mesh type through the digitizing process. These images were registered to geographical corrected satellite images with conformal conical projection by using GCPs. Thus, the water level and volume in each lake were calculated, and its changes were investigated in detail by comparing the isobathymetric images at the object years.

The evaporation based on Penman method (Kondo, 1994) and the calculation of precipitation in lake were carried out using the water area data from satellite image and the meteorological observations from datasets of World Monthly Surface Station Climatology by National Center for Atmospheric Research (NCAR) (Spangler, 1990).

Finally, the changes of water balance in Aral Sea and Lake Balkhash based on equation (1) were discussed with referring to the graphs described the relationship among the changes of lake water volume, evaporation, precipitation on lake area and inflow volume from surface. Moreover, Authors mentioned the relationship between lake change and environmental change at a continental scale through the comparative analysis of meteorological observations.

3. Change in water volume of Aral Sea and Lake Balkhash

The changes in water volume of Aral Sea and Lake Balkhash analyzed with satellite data, bathymetric map and other maps were described in figure 2. The solid line and broken line show the change ration of each year to 1960 of water volume and area respectively, because their changes before 1960 indicated little.

The water area in Aral Sea and Lake Balkhash shrank to about 57% and 89% respectively, and these respective volume decreased to under 25% and about 83%. The change in volume of Lake Balkhash indicated comparatively gradual decrease as well as the shrinkage in water area. Especially, the change was a little within the last a few years. However, it was clarified that the water volume of Aral Sea had become less than a quarter due to more amount of water loss than that of the assumption by the water area change. It is considered that the difference between both basins, which are the complicated relief of bottom of Aral Sea in contrast with the shallow and gradual one of Lake Balkhash, affects each change situation. The images for water depth of Aral Sea and Lake Balkhash composed of satellite data in land and shades corresponding to depth in lake are shown in Figure 3 and 4 respectively. These show that the depth distribution is largely different in the east and the west of the inland in Aral Sea, that is, the deep geographical features in lake of the west side contrasts with the shallow one of the east side.

The above results mentioned that the analysis using actual water volume is important to investigate the change in water balance of closed lake in detail.

4. Change in water balance of Aral Sea and Lake Balkhash

4.1 Water balance of Aral Sea

Figure 5 shows the water balance of Aral Sea based on equation (1) using satellite data, bathymetric map, geographical information data and meteorological observations. The water volume and inflow from the surface indicate the rapid decrease in contrast with a little change in precipitation and evaporation on the lake. On the other hand, the inflow from surface had shown remarkable decrease from the latter half of 1970's to beginning of 1980's, which became the tendency of gradual decrease since then. Therefore, it is presumed that most of decrease in lake water volume was caused by the decrease of inflow from the surface, if the change in inflow/outflow of underground is comparatively constant.

The precipitation in the drainage area of last about 40 years showed the tendency of almost unchanged or a little increase in the same manner as that of unchanged or a little rising in temperature. In the above points of view with the fact of the increase in the irrigated field along inflow rivers, it was clarified that the shrinkage of Aral Sea was most of the artificial effect and few effect by natural variation.

4.2 Water balance of Lake Balkhash

Figure 6 shows the water balance of Lake Balkhash based on equation (1) using satellite data, bathymetric map, geographical information data and meteorological observations. In contrast with the gradual decrease of water volume, a little change in precipitation for the last about 30 years, and decrease until the first half of 1970's and a little increase since then in the evaporation are indicated. Moreover, the tendency of decrease in inflow water became more gradual after the latter half of 1970's as compared with before then. Because the precipitation in the drainage area for the last about 40 years is the tendency of unchanged and the temperature is that of a little rise, it is assumed that these phenomena affect the change in evaporation.

In consideration of the above results with the fact for the expansion in the irrigated field along inflow rivers, it is assumed that the human activities until the first half of 1970's and natural variation of the gradual temperature rise with the artificial one after that affect the change in hydrological environment.

5. Conclusion

In this report, the change in water volume for the closed lakes of Aral Sea and Lake Balkhash in arid and semi-arid region were firstly calculated by analyzing the satellite images of water area change with bathymetric map and geographical information data. Next, the hydrological changes in both lakes were examined by the investigation of the water balance

referring to the meteorological observations. Based on the results, authors were able to investigate the detailed change situation in lake water volume, and detected the remarkable decrease in the volume of Aral Sea in especial. According to the above mentions, it is considered that the investigation of water volume is important to examine the water balance of closed lake in arid and semi-arid regions. Moreover, the change in Aral Sea affected by human activities and the change of Lake Balkhash affected by human activities with natural variation were presumed through the actual investigation of water balance.

The change in closed lake responds to the environmental change within the drainage area intensively, because a lot of various lakes, whose drainage areas are close with each other, distributed in arid and semi-arid regions of continents. Therefore, it can be considered that the change situation in closed lake has the possibility to used for an index of the change in drainage area, and it becomes effective information for the environmental change of arid and semi-arid regions. The continuous investigation for changes in closed lake with the landcover and snow cover within their drainage area is important to monitor the environmental change of arid and semi-arid regions.

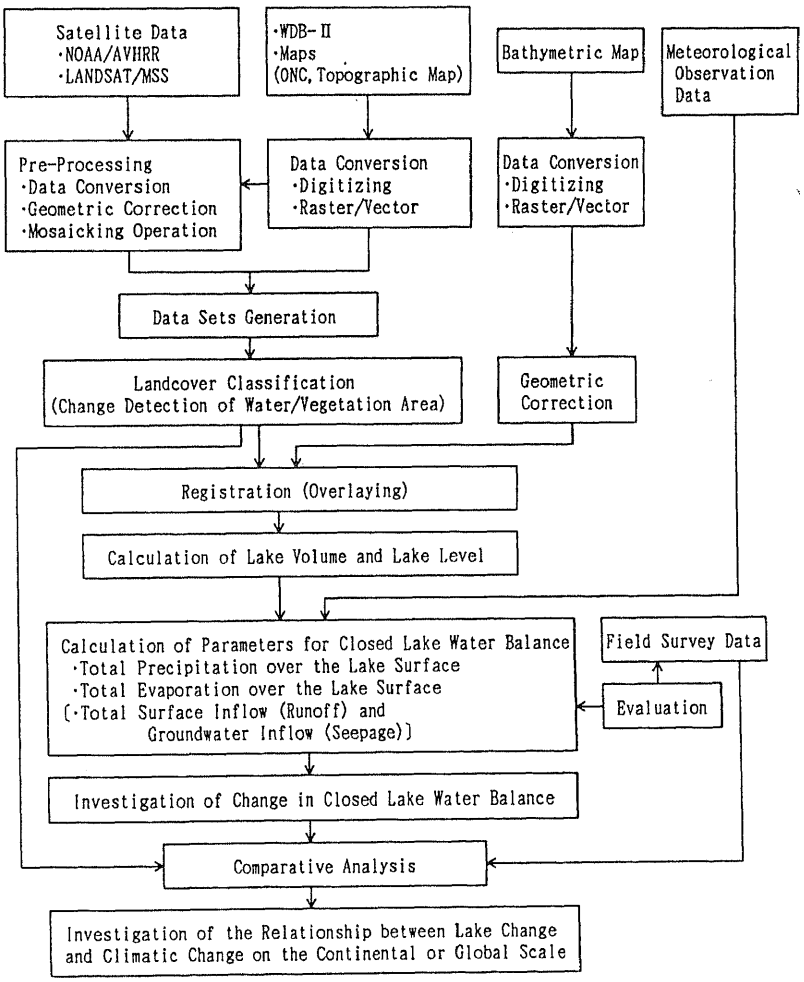

Figure 1. A flow chart for investigation of the change in the water balance of closed lake by satellite data, Bathymetric map and other sources.

Acknowledgments

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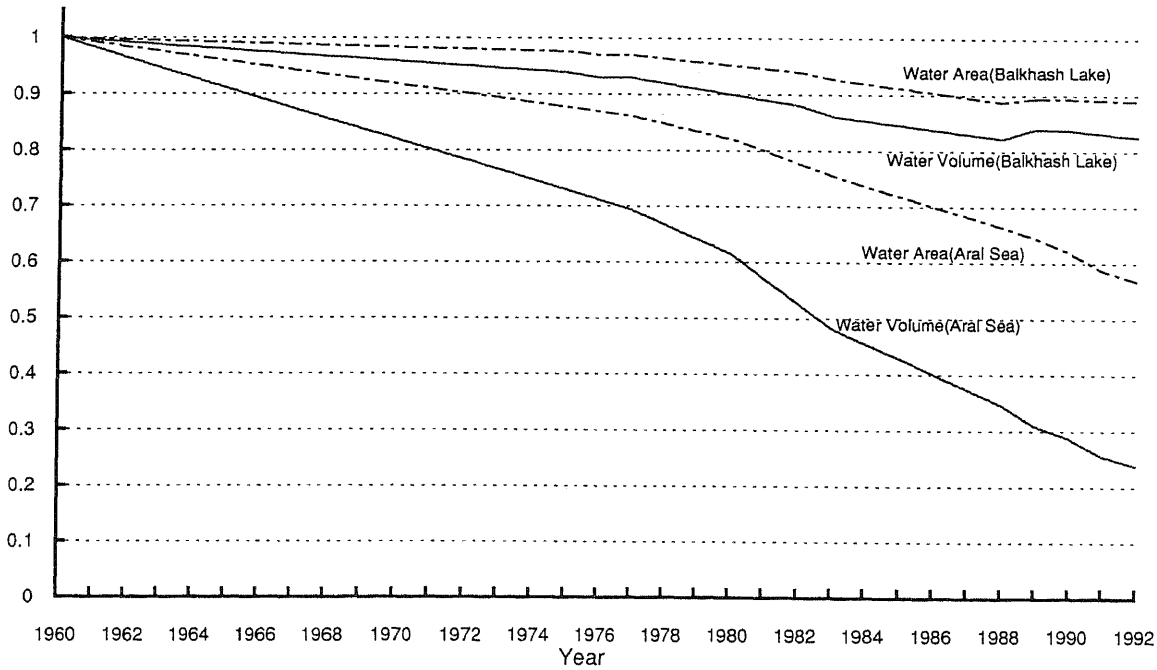

Figure 2. Changes in water volume and area of Aral Sea and Lake Balkhash. The solid line and broken line show the change ration of each year to 1960 of water volume and area respectively.

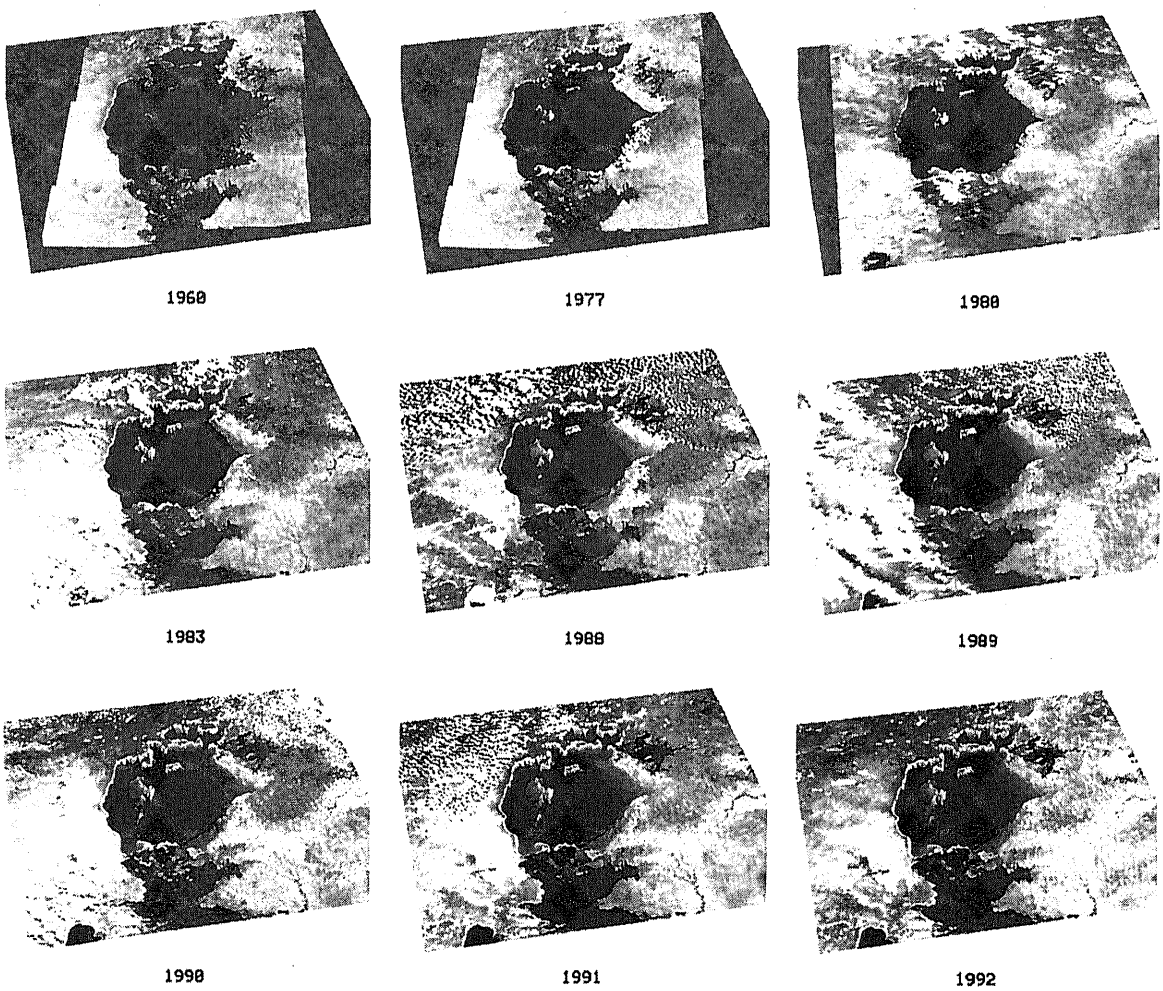

Figure 3. Change situation in water depth of Aral Sea from 1960 to 1992 based on satellite data and bathymetric map. Each image consists of satellite data in land and shading image based on bathymetric map.

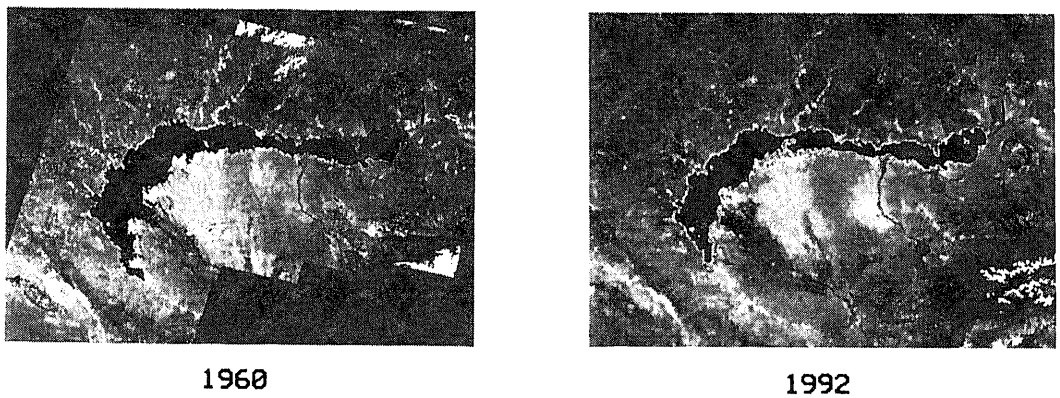

Figure 4. Change situation in water depth of Lake Balkhash at 1960 and 1992 based on satellite data and bathymetric map. Each image is similar to that of Aral Sea.

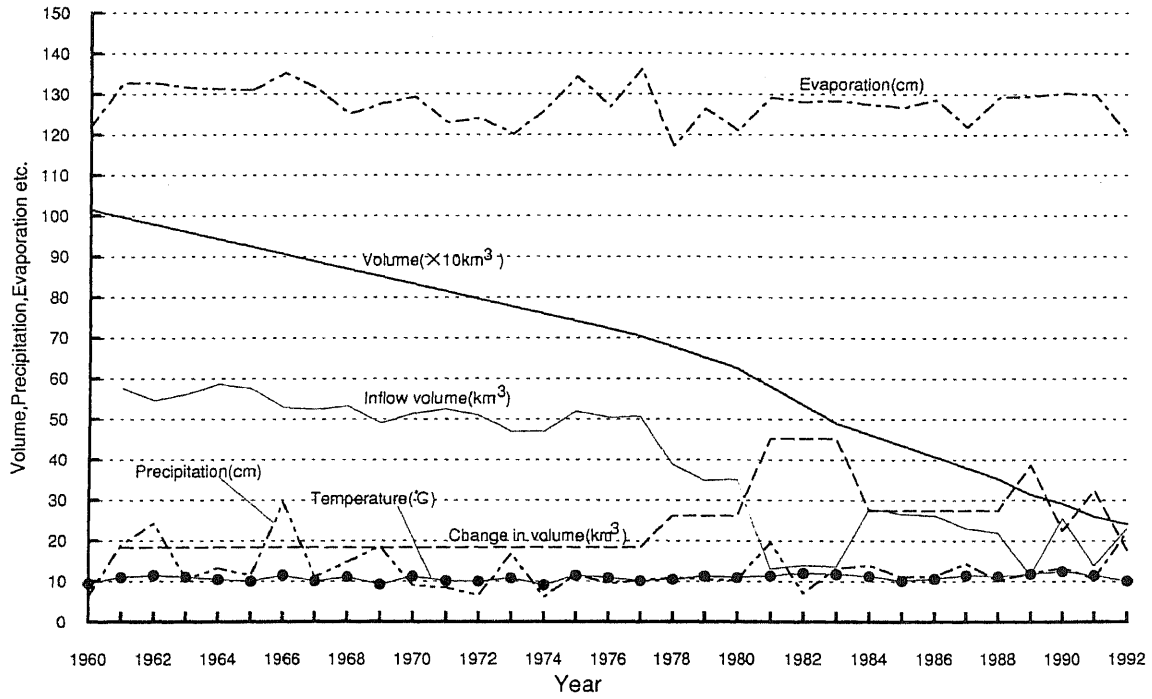

Figure 5. Change in water balance of Aral Sea.

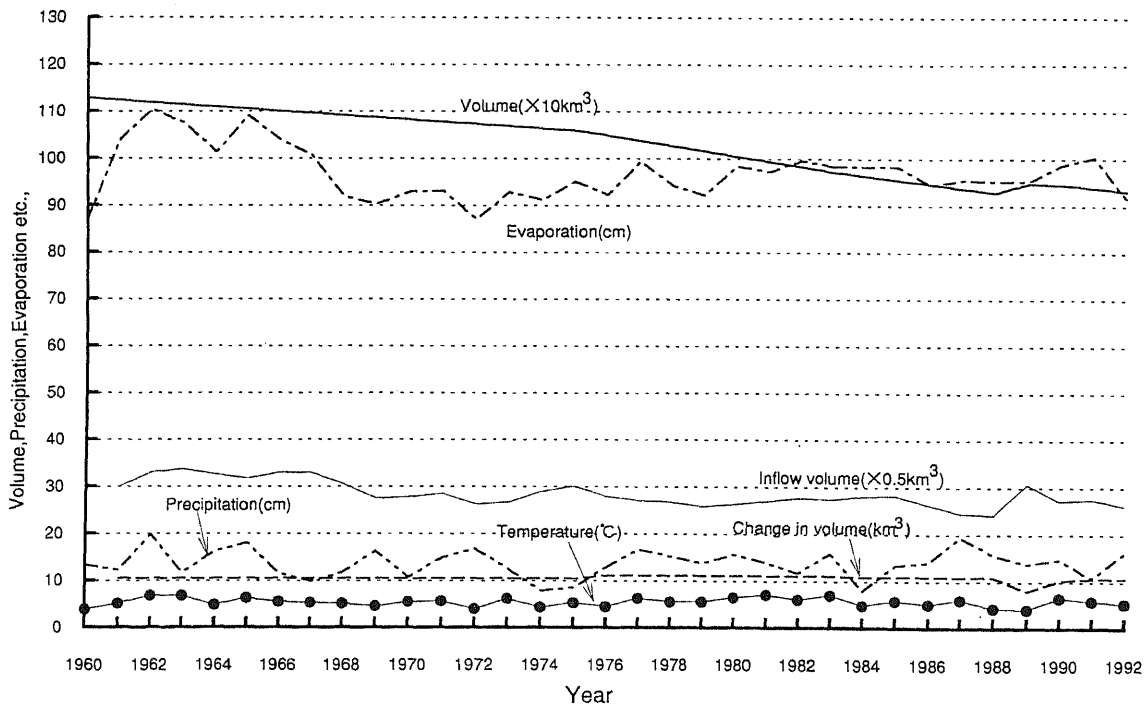

Figure 6. Change in water balance of Lake Balkhash.