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ANALYSIS OF WATER-LEVEL FLUCTUATIONS IN AYDARKUL-ARNASAY-TUZKAN LAKE SYSTEM AND ITS IMPACTS ON THE SURROUNDING GROUNDWATER LEVEL

Sri Wahyuni[1], Satoru OISHI[2], Kengo SUNADA[3], Toderich K.N.[4] and Gorelkin N.E[5].

[1]Student member of JSCE, PhD student, Dept. of Civil Eng., Univ. of Yamanashi (Kofu, Yamanashi 400-8511, Japan)
[2]Member of JSCE, Dr. of Eng., Associate Prof., Dept. of Civil Eng., Univ. of Yamanashi (Kofu, Yamanashi 400-8511, Japan)
[3]Fellow of JSCE, Dr. of Eng., Prof., Dept. of Civil Eng., Univ. of Yamanashi (Kofu, Yamanashi 400-8511, Japan)
[4]Dr., ICBA-CAC, Samarkand Division of the Academy of Sciences (3, Timur Malik Street, Samarkand 703000, Uzbekistan)
[5]Dr., Professor, Research Institute of Hydro-Meteorology of Uzbekistan (72, Murtazaeva Street, Tashkent 700000, Uzbekistan)

This paper presented the water level fluctuation in Aydarkul-Arnasay-Tuzkan Lake System (AALS) and its impact on the surrounding groundwater level. A positive correlation between the increasing of water surface area as a function of water level and the groundwater level was found. The water level has been fluctuating within 0.1–2.9 m/year and has been causing the increases in water surface area and groundwater level within 71–77 km^2/year and 0.05–0.16 m/year respectively. Regarding to high variability of arid climatic parameters, they gave significantly impact on the quality and the mineralization of both surface and groundwater. The schematic map of dynamical water surface and groundwater flow was drawn to provide better understanding the mechanisms of the fluctuation of water level, the increasing of mineralization and its consequence. It should seriously be considered by the following researchers and stakeholders.

***Key Words**: Uzbekistan, AALS, water level, water surface area, groundwater level, salinity.*

1. INTRODUCTION

Aydarkul-Arnasay-Tuzkan Lakes System (AALS) is an artificially man-made ecosystem created within the last 40 years on the former Aydarkul desert salt depression, which currently includes huge areas of floodplains, sandy degraded rangelands, rainfed and insignificant irrigated agricultural lands in the middle stream of Syrdarya River basin (Ladigina *et al.*, Kholmatov *et al.*)[1,2]. Historically these three large tectonically formed lakes were used for different purposes. In the Arnasay Lake due to its geomorphology water is low salinity, which is available for irrigated agriculture. The water of Aydarkul and Tuzkan are high mineralized because of discharge saline wastewater generated from the irrigated field and from collector-drainage system (Evelynn *et al.*)[3].

Since 1967, the AALS has regularly received water from the Syr Darya River as retarding basin through Chardara Dam, which constructed in early 1960s at the Uzbek-Kazakh boundary. The dam is provided with floodgates functions as flood control. In 1969, the increasing of AALS water level was occurred as a result of catastrophic outflow of water from Chardara reservoir. The floodgates were opened to prevent the dam from overflowing. Then, the over surplus of water was drained into the Aydarkul depression. During 1969 about 25 km^3 of water was released into the Aydarkul depression (Kitaykin *et al.*)[4].

The analysis of multi-years observation of the water level data indicated that water level in the AALS increased progressively every year (Alanazarova *et al.*)[5]. The increasing of AALS water level was observed within the period from 1993 up to 2007 and within that period the areas had been increased from 3,039 km^2 up to 3,748 km^2 (Alanazarova *et al.*)[6]. During last decades, it has been extending into 300 km in length and between 30 km and 50 km wide. Therefore the AALS becomes the next famous after Aral Sea world’s best known (Alanazarova *et al.*)[5,6]. The increasing of water level of AALS induced the flooding of rangelands, allocated for livestock grazing (Gintzburger *et al.* and Kawabata *et al.*)[7,8].

The United Nations Environment Program/The Global Resources Information Database (UNEP/ GRID) stated that the most serious problem occurs in the Dzhizak Oblast (one of the province in Uzbekistan) is the AALS water level fluctuation [9].

The assessment done by Veselov *et al.*[10] and Takhirov *et al.*[11] for the Aral Sea Basin, including AALS showed that the increasing of surface water level of AALS followed by intensive evaporation in summer induces the changes in the water quality and mostly on the ion mineral composition both of surface and groundwater. Other researcher also proposed a series of water modeling and scenarios for integrated water resources management for wetlands restoration (Dukhovny *et al.*)[12]. However the previous researchers paid not enough attention on the seasonal and multi-annual fluctuations and water surface level. And a little attention has been drawn to the evaluation of surface water level, factors of increasing its mineralization, ground water budget and impact of mineralization of both surface and ground water to the entire ecosystem.

This study is the first attempt which concisely provides information on the seasonal and multi-annual fluctuations of water level in AALS and the evaluation on their associated impacts. These are necessary for local practitioners and policy makers towards sustainable water management in AALS.

The most important findings and the necessity data to be used for further researchers and local practitioners are:

1. development new artificial ponds caused by groundwater level changes in the vicinity area.

   Since the lake is saline, it leads to increase the salinity problem and vegetation changes at surrounding area. Therefore, it is necessary for policy makers to keep sustainable inflow from Chardara reservoir,
2. schematic map of dynamical water surface and groundwater flow.

   It is useful for local practitioner as rapid assessment for impact analysis and sustainable water management in AALS,
3. review on the groundwater changes and salinity as part of impacts of increasing water level in AALS within recent periods,
4. relationship between water level (H) and lake area (A) to predict the extension of flooded area.

These are novelties of this study, since there are no such kinds of outcomes so far.

2. STUDY AREA

Target area constitutes lakes Aydarkul, Arnasay, Tuzkan and surrounding desert territories, located at south-western part of Uzbekistan. As shown in **Fig. 1**, the AALS in the north is bounded by the Kyzylkum sandy desert. In the south it is bounded by the foothills of the North-Nuratau Mountains, while massive territories of Mirzachuli (Golodnaya steppe) bounded it in the east. The total length of the AALS is 300 km and its width ranges 30–50 km[5,6].

3. DATA AND METHODOLOGY

The lake's water level, lake's water surface area, lake's water volume, groundwater level data in the neighborhood and inundation map of the lake for the past years were obtained from the Research Institute of Hydro-Meteorology of Uzbekistan[13], while the satellite images were acquired from the Terra MODIS[14].

(1) Water level, water surface area, and water volume of the lake

The historical data of the lake water level were obtained from two sources. The first one included monthly water level for the period 1984 to 2004[13].

The second source comprised the annual water level data from 1993 to 1999[15]. The water surface area and lake's water volume were analyzed on the basis of the observation data recorded from 1993 to 1999[15]. An inundation map for 1987 (**Fig. 2**)[13] was used as a reference for identifying the fluctuations in the surface water level of the lake during a certain following period.

(2) Satellite images to calculate water surface area

The satellite image recorded onboard of the Terra MODIS was obtained from the global data of the National Aeronautics and Space Administration (NASA). The publicly available images (resolution 250 m) of the study area between 2003 and 2004 were used for verifying the observation data. The satellite images from Terra MODIS for a clear-sky day were selected.

Fig.1 Location and boundaries of the AALS.

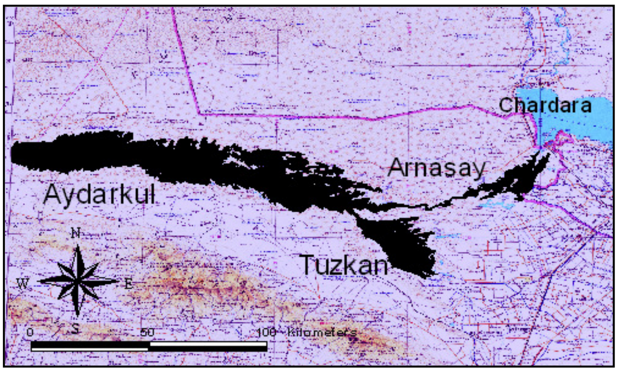


Fig. 2 Map of the AALS based on a 1987 survey.

The method for calculating the water surface area is described as follows. A hard copy map of the lake's water surface for 1987 was digitized and georeferenced. Thus, the water surface area was calculated by mean of GIS. The conventional method for determining the water body from the satellite images is done by using the normalized difference water index (NDWI); however, NDWI requires at least six bands of spectrum. On the other hand, the normalized difference vegetation index (NDVI) can also be used to delineate the water body. NDVI is defined as (near IR band – red band)/(near IR band + red band). For Terra MODIS, the *NDVI* is calculated as follows (Wang)[16]:

$$NDVI = (B2 - B1)/(B2 + B1), \qquad (1)$$

where $B2$ is band 2 (near infrared (NIR): 841–876 nm) and $B1$ is band 1 (red: 620–670 nm). Generally, NDVI values range from +1 (maximum vegetation) to –1 (no vegetation). Water body areas correspond to NDVI values close to 0. Finally, the water surface of lake's area was calculated, then it was compared with the observed data.

(3) Groundwater level

The groundwater level data in the area surrounding the lake are required for assessing the influence of water level fluctuation of the lake to the groundwater level. The available data (1993-2006) was collected from two wells in the region surrounding of the lake.

4. RESULTS AND DISCUSSION

(1) Fluctuations in the water level

The observations of the lake's water level system carried out by the Research Institute of Hydro-Meteorology of Uzbekistan, RHMI[13] are shown in **Fig. 3**. It appears that the considerable increase in the water level of the AALS has been started since 1991. The water level was 237 m BS (relative to the mean Baltic Sea Level) in the early 1990s, and it increased to 246 m BS by 2004. Before 1991, the annual increase in the water level varied in the approximate range 0.01 m–0.24 m. However, after the 1990s, the range dramatically increased to 0.04 m–2.93 m. These values are almost 4–8 times higher than the pre-1991.

In 1994, the discharge of the excess water of the Chardara Reservoir released into the AALS reached the maximum value. This inflow from Chardara Reservoir was almost 3.5 times of the annual inflow in 1993. This high inflow significantly affected the water level increase in that year, which was higher by almost 3 m as compared to that in 1993. As results, the inflow in 1994 was the highest in the 10-year period (1994–2004). The annual inflow in this lake system varied from 0.04 km^3 to 6.63 km^3.

(2) Increase in the AALS water surface area

By utilizing data from the different sources[15], the fluctuation of water level in the AALS is shown in **Fig. 4**. Started from 1993 to 1999, the water level, water surface area and water volume of the lake progressively increased.

With additional data from Kityakin *et al.*[4] studies, the relationship between the water level (H in m BS) and the water surface area (A in km^2) could be expressed by a simple linear equation of the form:

$$A = a\,(H - H_0) + A_0, \qquad (2)$$

where a (165.09) is a constant, H_0 (235.68 m BS) is the known water level for 1984, and A_0 (1714.4 km^2) is the water surface area for 1984. The coefficient of determination (R^2) was 0.97 (**Fig. 5(a)**).

In fact, increase in the water surface area occurred only on single side i.e., toward the northern part. Kyzylkum desert is located in the northern part and desert has mild slope topography which is almost linear (i.e. the area has continuously uniform slope from mild to flat within single direction).

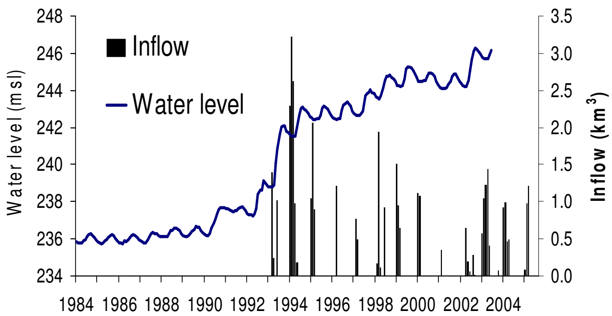
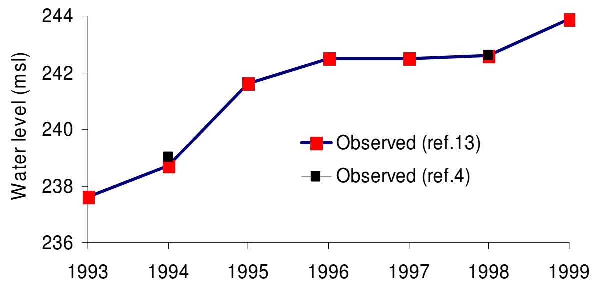
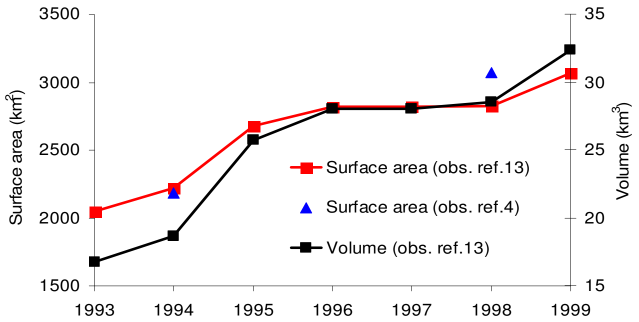


Fig. 3 Variation of the water level and inflow into the AALS.

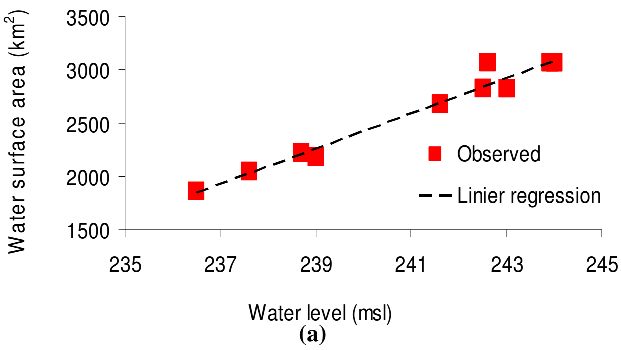


(a)

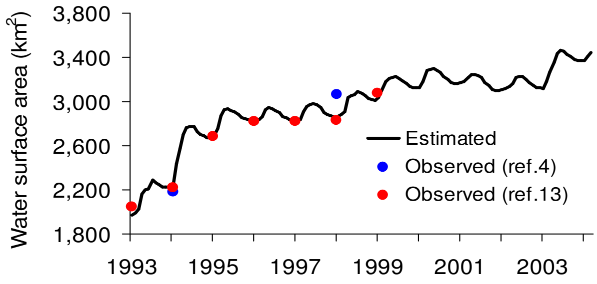


(b)

Fig. 4 Fluctuation in the water level (a), water surface area and water volume of the AALS (b).

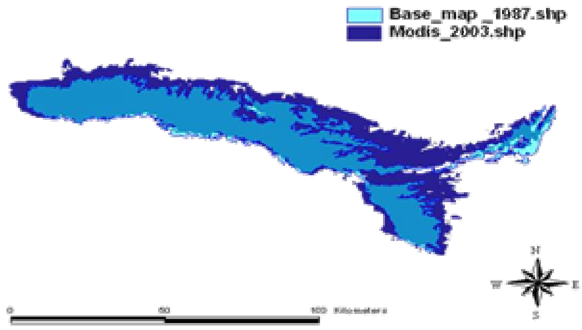


(a)

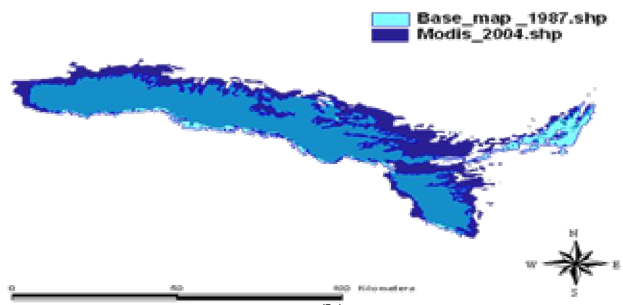


(b)

Fig. 5 (a) Simple linear regression of the increase of the water surface area of the AALS.
(b) Estimation of the monthly water surface area by simple linear regression.



(a)



(b)

Fig.6 Increase in the water surface area of the AALS in 2003 (a) and 2004 (b) compared with the increase in 1987.

On other hand, the southern part of lake is bounded by Nuratau Mountain in which topography is nonlinear (i.e. the area is undulating surface with non uniform slope at any directions). Thus, this simple equation sounds useful and adequate for predicting future trend of the increasing in water surface area.

The water level data were partly verified with the observed monthly data[13)]. The estimated water surface area is shown in **Fig. 5(b)**. It means that for every 10-cm increase in the water level, the water surface area will increase by approximately 17 km^2. The increase in the water surface area was apparent also in the comparison between the 1987 survey and recent satellite images of Terra MODIS. The changes in the water surface area are shown in **Fig. 6**. Since NDVI for water surface is normally negative, in this calculation, negative value of NDVI (close to 0) is used for indicating presence of water body. NDVI is near zero positive value for clouds and bare soil. The NDVI method clearly delineated the water body in the study area. The site visit in August 2007 revealed that the area surrounding the lake (**Photo 1)** was almost without vegetation as well as indicated by NDVI values.

The detail of the increase in the water level and water surface area was given in the **Table 1.** The change in the water surface area from 1987–2006 was approximately 1,456 km^2 or 76 km^2/year. In 1987, the water surface area was approximately 2,246 km^2. In the early 1990s, the water level reached an elevation of 237 m BS.

An analysis of the satellite images for 2003 and 2004 showed that the water surface area and the water level increased to 3,450 km^2 and 246.2 m BS, respectively. These results were well agreeing with the observed data[13)], which indicated that the water level reached an elevation of 246 m BS by 2004 and estimated the water surface area to be 3,418 km^2.

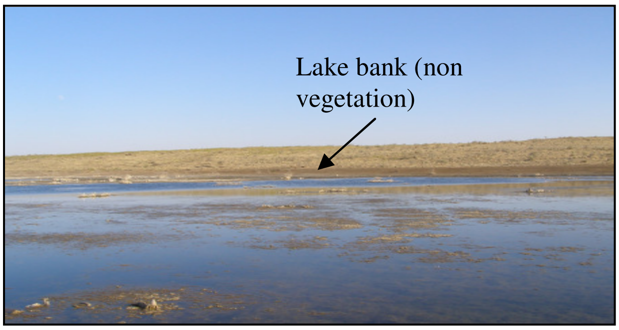


Photo 1 Portion of AALS and its surrounding environment as observed during the site visit in August 2007.

Table 1 Portion data of increasing water surface area of the Aydarkul-Arnasay Lake

Source data	Date (yy/mm/dd)	Lake area (km^2)	Changes relative to 1987 (km^2)	Remarks
Base map	1987	2246	-	Total water from the Chardara Reservoir entering the lake was higher in 2003 than 2004.
Terra MODIS	2003/02/03	3352	1106	
	2003/06/10	3522	1276	
	2004/06/20	3457	1211	
RHMI, Uzbekistan	2006	3702	1456	

In 2006, the water surface area was around 3,702 km^2, with a volume of 44.19 km^3 in the same year. The water level again increased and reached an elevation of 247.7 m BS in 2006. In general, the estimation of the water surface area by using the linear regression equation was enough reliable. A comparison of the water surface areas obtained from observed data, satellite images, and the simple linear equation is shown in **Table 2**.

(3) Hydrodynamical data for groundwater level in the area surrounding the lake

Fig. 7 shows the location of two observation wells during 1993–2006, namely No. 141 and No. 142. They provided the monthly groundwater levels associated with the fluctuations in the water level of the lake as shown in **Fig. 8**. The wells situated at approximately 11 km (well No. 141) and at 7 km (well No. 142) from the lake boundary. The distance between the observation wells was approximately 21 km. In the well No.141, the surrounding groundwater level changed from 12.06 m to 9.28 m below the surface (difference of 2.78 m). Meanwhile, in the well No. 142, the data showed that the surrounding groundwater level changed from 2.94 m to 0.5 m below the surface (difference of approximately 2.44 m). They were anomalies between 1998 and 1999.

Table 2 Comparison of the water surface area

Year	Water level (m BS)	Water surface area (km^2)
1987	-	2,246 (D)
1990	237.00 (D)	-
2003–2004	246.20 (EE)	3,450 (ES)
2004	246.00 (D)	3,418 (EE)
2006	247.72 (EE)	3,702 (D)

D = Data, EE = Estimated using equation, ES = Estimated using satellite image

By statistical trend analysis, the annual increase of the trends were 0.16 m (well No.141, with R^2 = 0.80, statistically surely increase) and 0.05 m (well No.142 with R^2 = 0.26, statistically increase even though it is small).

From 2001 to 2006, the trend of the groundwater level was not very clear. This was because of the groundwater in well No. 142 reached nearly the land surface. When the groundwater reaches the land surface, it will rise to the following effects: (1) increase in the lake water surface area (if the area is close to the lake main body) and (2) creation of new ponds (if the area is far from the lake). Meanwhile, well No. 141 reached the saturated condition or steady state.

The schematic of dynamical water surface movement and estimated groundwater penetration was drawn. Along with topographical situation, the increasing water level tends to push groundwater moving to northern parts. These mechanisms and its consequences should seriously be considered by following researchers and stakeholders.

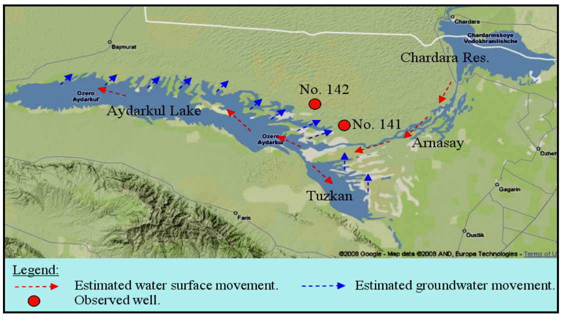


Fig.7 Locations of observed wells and the schematic diagram of dynamic of water surface and groundwater in AAL

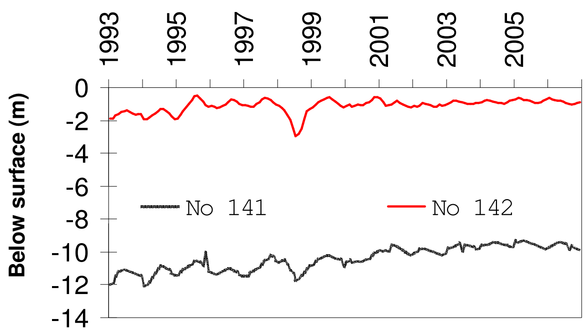


Fig.8 Observation data of groundwater level at surrounding lake

(4) Effects of increase in lake water level on water surface area and groundwater level

The observed data showed that water salinity in these wells were 5 g/L (well No. 141) and 3 g/L (well No. 142). Since the lake is saline, an increase in groundwater level tends to increase salinity in the vicinity due to leaching and evaporation processes.

The increasing of lake water level has induced the fluctuation in the groundwater level both along Aydarkul Lake side and surrounding area. Uncontrolled discharge from these sources has resulted in the development of artificial ponds and with very high evaporation rates during the summer months these ponds dry out with the formation of crystallized salts. In addition, poor natural drainage network systems of marginal cropped irrigated lands has caused an increase in the salt content of surface soils and groundwater that has induced secondary salinization of the soils surrounding AALS.

Soil salinity is a very serious problem in some agricultural irrigated lands locations of Arnasay-Tuzkan shore areas due to groundwater, resulting from excess irrigation during crops cultivation, high evaporation during hot summer and/or poor drainage. Due to the gradual increase in soils salinization and rising of water table, the lands majority in cropping farms in Aydarkul-Chardara trounsboundary areas have been gradually removed from traditional agricultural crops cultivation.

5. CONCLUSION

A positive correlation between the increasing of water surface area as a function of water level and the groundwater level changes at surrounding area of AALS was found. Currently, the water level of AALS has been increasing up to 2.9 m/year and caused increase of groundwater within 0.05–0.16 m/year. Since the lake is saline, an increase in the groundwater level will increase the salinity in the vicinity. Relationship between water level (H) and lake area (A) was determined. NDVI did efficiently for identifying an increase in the lake area of AALS.

The schematic map of dynamical water surface and groundwater flow was drawn to provide better understanding of water level fluctuations mechanisms, causes for increasing of water mineralization and its consequence. It should seriously be considered by following researchers and policy makers towards sustainability of water management in AALS.

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