An Ecological Disaster of the Aral Sea

***Behzod Gaybullaev*[(1)] *, Su-Chin CHEN* [(2)]*, Tohir Mahmudov* [(3)]**

PhD Research Fellow[(1)], Professor and Chairman [(2)], Department of Soil and Water Conservation, National Chung Hsing University, Taichung 407, Taiwan, R.O.C.

Researcher[(3)], Institute of Genetics and Plant Experimental Biology, Academy of Science, Tashkent, Uzbekistan

Abstract

This study examined the effect of psychosocial factors and ecological perceptions on self-rated health in the ecological devastated Aral Sea area of Karakalpakstan. The Amudarya and Syrdarya delta region contains surface and groundwater resources that discharge into the shrinking Large Aral Sea and ultimately control its future fate. These freshwater resources are prerequisites for sustaining the population of the region. However, salinization and pollution caused by agricultural irrigation is a key problem for these water systems. Here, we report results from a recent field measurement campaign conducted during April 2005 which included 24 monitoring wells located in an irrigated region of the Amudarya delta, thereby extending the historical data set of groundwater levels and salinity measurements. This data set is combined with corresponding data from a downstream, non-irrigated region that was formerly irrigated (together covering 16,100km^2 between the Uzbek cities of Nukus and Muynak). This comparison shows that in the downstream region, which is currently not irrigated, shallow groundwater are far more saline (average 23g l/l) than the currently irrigated region (average 3g l/l).. We estimate that the unconfined aquifer within the 13,500km^2 non-irrigated zone of study area contains 9 billion tons of salt, or almost as much salt as the entire Aral Sea (containing 11 billion tons of salt and covering an area of 20,000km^2 in year 2000). Within the non-irrigated zone, there are statistically significant large-scale spatial correlations between groundwater salinity and distance to the Amudarya River, irrigation canals and surface water bodies when distance is measured along the modeled regional groundwater flow direction. Generally, groundwater salinities are lower downstream of surface water bodies in the non-irrigated zone. Annual fluctuations in groundwater salinity are too large to be explained by input from surface water (Amudarya) or wind-blown salt from the dried Aral Sea sediments. Salt transport by groundwater is the only plausible remaining explanation for these changes.

---

(1) 國立中興大學水土保持學系博士後研究員
(2) 國立中興大學水土保持學系教授
(3) 研究員

水土保持學報 41(3)：325-338 (2009)
Journal of Soil and Water Conservation, 41(3)：325-338 (2009)

(**Key words:** Aral Sea; Irrigation; Surface water; Water systems; Salinization; Solution; Pollution; Groundwater, Ecological disaster)

Introduction

One of the most dangerous areas of ecological disasters in Central Asian region was created on drying up of the Aral Sea due to acute shortage of water resources. It also developed in an area of great pollution, desertification, and aggravation of land resources and vanishing of biological resources, which caused threat for steady development of the region. On the ecological and socio-economic effect, the problem of the Aral Sea represents one of the largest disasters of 20th century [1]. Any ecological problem, including Aral tragedy, infringes interests of nation, therefore an attention of a majority of a public conversion to it [2]. Until the middle of 20th century the Aral Sea was the fourth in the world on the dimensions among self-contained pools. For many centuries, the two rivers – Amudarya and Syrdarya divided the water between an irrigation of arid eremic oases and Aral Sea [3]. Five independent states –Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, and Turkmenistan, and also Afghanistan, are located on the territory of the Aral Sea basin. The basin located at the center of Central Asian deserts and it is giant vaporizer of about 60 km^3 water per year entered in an atmosphere until recently, thus it was large climate-forming, temperature-controlling factor. Besides the sea was a huge receiver of salts, carried out in it by the rivers. The Aral Sea and the Aral Sea region problems initially originated as a common ecological problem, at present have grown into the problem of man's ecology, health and life in the conditions of anthropogenic desertification. The centuries-old stable ecosystem breakdown takes place. The high productive unique natural complexes become extinct, the priceless natural resources of endemic flora and fauna are irretrievably lost [4].The destruction of the sea and its ecosystems constitutes one of the greatest man-made environmental disasters in history. The ecological catastrophe has been associated with a sharp decline in the health status of the human population in the region. The environmental deterioration is expected to continue and the health outlook is similarly grim. There is a requirement for immediate health related assistance from the international community.

The Aral Sea is a landlocked endorsees basin in Central Asia; it lies between Kazakhstan in the north and Karakalpakstan, an autonomous region of Uzbekistan, in the south.

The problem of ecological security remains acute because of the tragedy of the drying up of the Aral Sea, and the industrial pollution of our environment.

Background

Once the world's fourth-largest Land Sea with an area of 68,000 km², the Aral Sea has been steadily shrinking since the 1960s, after the rivers Amudarya and Syrdarya that fed it were diverted by Soviet Union irrigation projects. By 2004, the sea had shrunk to 25% of its original surface area, and a nearly fivefold increase in salinity had killed most of its natural flora and fauna. By 2007 it had declined to 10%

of its original size, splitting into three separate lakes, two of which are too salty to support fish. The once prosperous fishing industry has been virtually destroyed, and former fishing towns along the original shores have become ship graveyards. With this collapse has come unemployment and economic hardship.

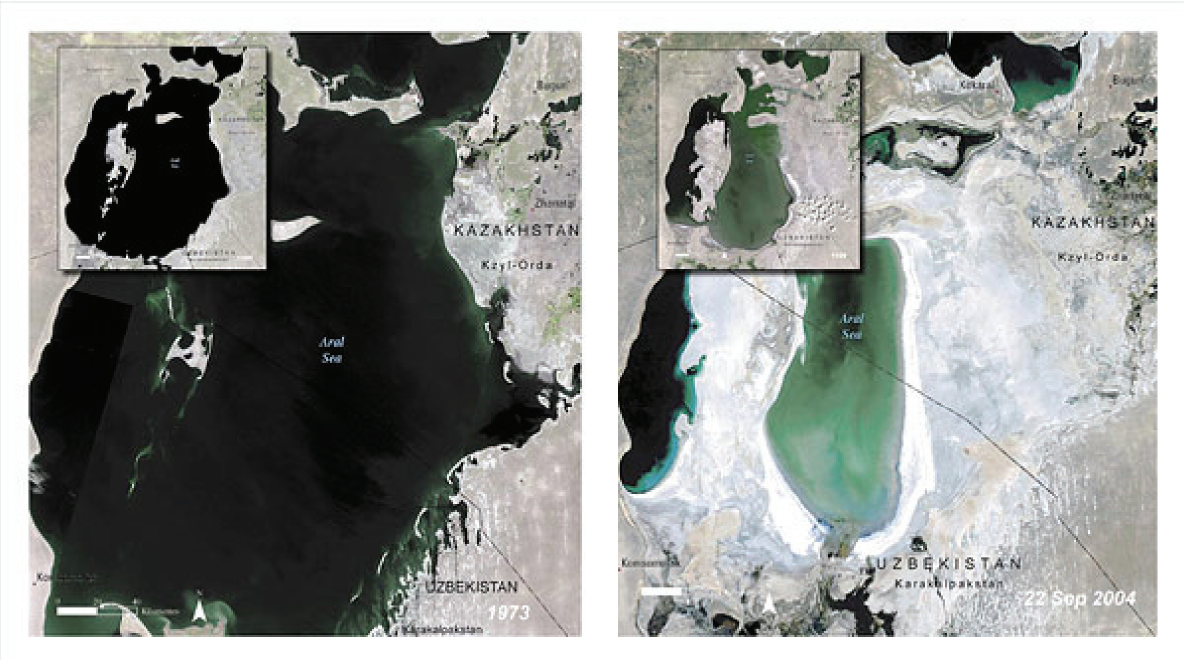


Figure 1. The Aral Sea basin in 1972 and in 2004, HEMP INFO, 2008

Figure 2. The Aral Sea basin in Central Asia, in 1960

The plight of the Aral Sea is frequently described as an environmental catastrophe. There is now an ongoing effort in Kazakhstan to save and replenish what remains of the northern part of the Aral Sea (the Small Aral). A dam project completed in 2005 has raised the water level of this lake by two meters. Salinity has dropped, and fish are again found in sufficient numbers for some fishing to be viable. The outlook for the far larger southern part of the sea (the Large Aral) remains bleak. Central Asia is landscaped by desert, semi-desert, dry steppes and high mountains. The Aral Sea is sandwiched between two deserts, the Karakum and the Kyzylkum. In the Aral Sea region, summer temperatures reach +40 ^{0}C and winter temperatures fall to -20 ^{0}C. Precipitation is minimal. The main volume of water comes from high glaciers feeding into the two main rivers, the Syrdarya and the Amudarya, which enter the sea from the north and south respectively. Historically, the Amudarya supplied about 70% of the Aral Sea’s water. The Aral Sea is bordered by Kazakhstan to the north and Uzbekistan to the south. The Aral Sea Basin includes Uzbekistan, Tajikistan, and parts of Kazakhstan, Kyrgyzstan, and Turkmenistan. Around the southern edge of the Aral Sea is the Karakalpakstan Republic, an autonomous republic incorporated into Uzbekistan. The people of Karakalpakstan, population approximately 1.5 million, are culturally and ethnically distinct from the rest of Uzbekistan and have borne much of the brunt of the ecological disaster.

The Ecological Problems

History

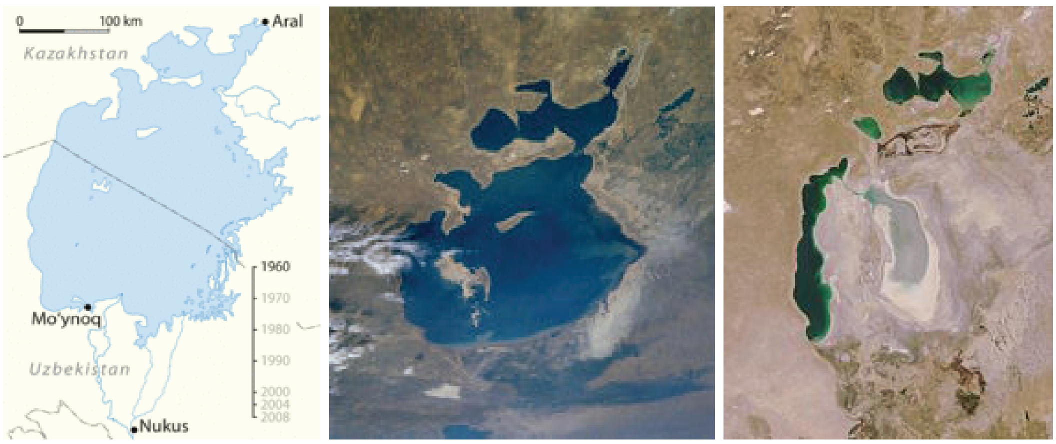
In 1918, the Soviet government decided that the two rivers that fed the Aral Sea, the Amudarya in the south and the Syrdarya in the northeast, would be diverted to irrigate the desert, in order to attempt to grow rice, melons, cereals, and cotton. This was part of the Soviet plan for cotton, or "white gold", to become a major export. This did eventually end up becoming the case, and today Uzbekistan is one of the world's largest exporters of cotton. The construction of irrigation canals began on a large scale in the 1940s. Many of the canals were poorly built, allowing water to leak or evaporate. From the Qaraqum Canal, the largest canal in Central Asia, perhaps 30 to 75% of the water went to waste. Today only 12% of Uzbekistan's irrigation canal length is water proofed. By 1960, between 20 and 60 cubic kilometers of water were going each year to the land instead of the sea. Most of the sea's water supply had been diverted, and in the 1960s the Aral Sea began to shrink. From 1961 to 1970, the Aral's sea level fell at an average of 20 cm a year; in the 1970s, the average rate nearly tripled to 50–60 cm per year, and by the 1980s it continued to drop, now with a mean of 80–90 cm each year. The rate of water usage for irrigation continued to increase: the amount of water taken from the rivers doubled between 1960 and 2000, and cotton production nearly doubled in the same period (Michael Wines 2002).

Current situation

From 1960 to 1998, the sea's surface area shrank by approximately 60% and its volume by 80%. In 1960, the Aral Sea was the world's fourth-largest lake, with an area of approximately 68,000 km² and a volume of 1100 km³; by 1998, it had dropped to 28,687 km², and eighth-largest. As of 2004, the Aral Sea's surface area was only 17,160 km², 25% of its original size. By 2007 the sea's area had shrunk to 10% of its original size, and the salinity of the remains of the southern part of the sea (the Large Aral) had increased to levels in excess of 100 g/l.

In 1987, the continuing shrinkage split the lake into two separate bodies of water, the North Aral Sea (the Lesser Sea, or Small Aral Sea) and the South Aral Sea (the Greater Sea, or Large Aral Sea); an artificial channel was dug to connect them, but that connection was gone by 1999 as the two seas continued to shrink. In 2003, the South Aral further divided into eastern and western basins. The loss of the North Aral has since been partially reversed (see below). Shrinkage of the lake also created the Aral Karakum, a desert on the former the water level of the North Aral has risen, and its salinity has decreased. As of 2006, some recovery of sea level has been recorded, sooner than expected. "The dam has caused the small Aral's sea level to rise swiftly to 38 m, from a low of less than 30 m, with 42 m considered the level of viability. There are plans to build a new canal to reconnect Aralsk with the sea. Construction is scheduled to begin in 2009, by which time it is hoped the distance to be covered will be only 6 km. A new dam is to be built based on a World Bank loan to Kazakhstan, with the start of construction also slated for 2009 to further expand the shrunken Northern Aral eventually to the withered former port of Aralsk. (UNDP, 2007, Micklin P., 2008,).

lakebed. Work is being done to restore in part the North Aral Sea. Irrigation works on the Syrdarya have been repaired and improved to increase its water flow, and in October 2003, the Kazakh government announced a plan to build Dike Kokaral, a concrete dam separating the two halves of the Aral Sea.



a).The shrinking of the Aral Sea b).Aral Sea from space, August 1985 c). Aral Sea from space, October 2008

Figure 3. Changing Profile of the Aral Sea 1960–2008.

Work on this dam was completed in August 2005; since then The ecosystem of the Aral Sea and the river deltas feeding into it has been nearly destroyed, not least because of the much higher salinity. The receding sea has left huge plains covered with salt and toxic chemicals, which are picked up and carried away by the wind as toxic dust and spread to the surrounding area. The land around the Aral Sea is heavily polluted and the people living in the area are suffering from a lack of fresh water and other health problems, including high rates of certain forms of cancer and lung diseases.

Study area and field measurements

Fig. 4 shows the study area, which covers approximately 16,100 km^2. As part of the study we will investigate the top part (5 m) of the unconfined aquifer, which is most likely to be affected by agricultural activities. The aquifer ranges in depth between 10 and 150 m. 90m Digital Elevation Data (Shuttle Radar Topographic Mission, National Aeronautics and Space Agency; http://srtm.csi.cgiar.org/, 2005-06-08) show that the elevation of the study area varies between 18 and 255 m, and most of the area is flat with an elevation of about 30 m. A large part of the study area was formerly irrigated. Today, only the southern part is used for irrigated agriculture (Fig. 3). The surface waters of the study area contain a significant amount of irrigational return-waters from upstream areas, which in turn are again used for irrigation. The area comprises wetlands that are important reserves for the remaining flora and fauna. Geologically, the area comprises dried-up sediments from the Amudarya River on top of Quaternary deposits. The aquifers contain gravel, sand, sandstone and loamy sandy sediments. The soil salinity ranges between relatively low and high. When the salinity is moderate to high, the soils are called solonchaks and are commonly characterized by saline crusts (Singer et al., 2001). The field campaign reported here is a continuation of the measurement series of the Karakalpak Hydro-melioration Expedition (KHE). We used 24 groundwater monitoring wells (capped steel pipes with a diameter of 10 cm encased in concrete rings) that were also analysed in the monitoring program of the KHE and are located in the currently irrigated area (see Fig. 4). In order to obtain comparable results, the groundwater sampling procedures used were consistent with those used by the KHE. More than 500 wells are currently administered by the KHE. In previous hydraulic evaluations carried out by the KHE, the investigated 24 wells showed intact hydraulic connection with the surrounding aquifer. The depth to the groundwater table was measured using a floating weight on a graded string. Groundwater salinity was measured with a portable conductivity meter. The groundwater samples analyzed for conductivity were taken in approximately 1 m below the groundwater table.

Groundwater hydraulics and salinity distribution

The inferred salinity distribution of groundwater in the irrigated area, based on measurements during the sampling campaign in 2005, is shown in Fig. 5.

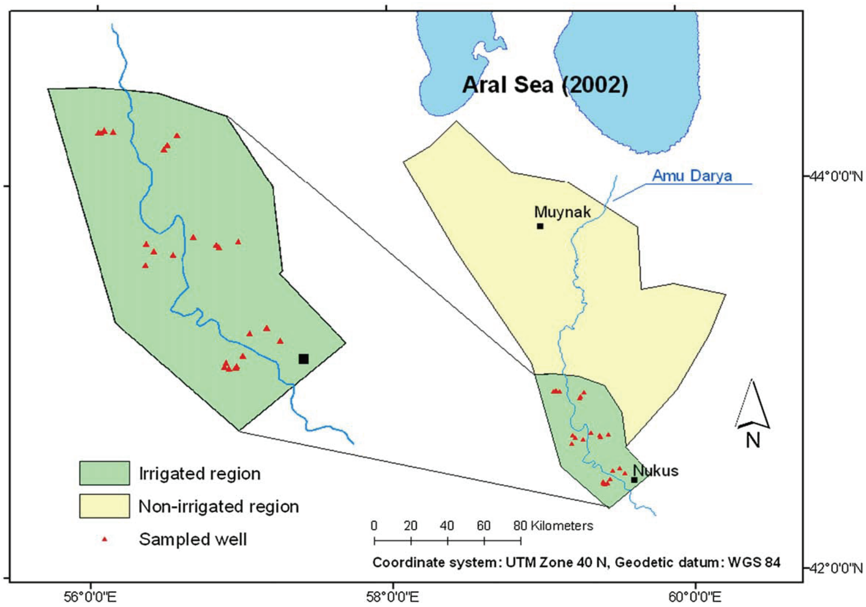


Figure 4. The study area, covering 16,100 km^2 within the Amudarya delta to the south of the Large Aral Sea, and its division into an irrigated part (green color) a non-irrigated part ((yellow color) May 2002).

For the entire region, the mean groundwater salinity is 2.7 g l/1, whereas it is as high as 17.8 g l/1 in its southern part.The lowest groundwater salinity was 0.78 g l/1; most of the wells showed much higher salinities. Water tastes salty above 0.25 g l/1. The Uzbek national maximum limit for drinking water is 1 g l/1, which means that most wells exceed this limit. The shallow groundwater of the study area is therefore not suitable for drinking water.

Fig. 6 shows local groundwater salinity values measured between 1990 and 1999 for the non-irrigated areas and between 1996 and 2005 for the irrigated areas. These results illustrate the possible effects of local hydrologic conditions, such as the proximity to the Amudarya River and engineered water systems such as irrigation or drainage canals. Groundwater salinities are positively correlated with the distances to the Amudarya and to abandoned irrigation canals (Fig. 6 a, b). Distance is measured along mean groundwater flow paths following the groundwater flow direction from the Amudarya (or the irrigation canal) to the groundwater observation well. Groundwater salinities are generally lower near the Amudarya and close to irrigation canals. Inter-annual salinity changes seem to weaken the correlation between salinity values and distances to the Amudarya or irrigation canals. The correlations distinctly improve at annual scale. In 1994, the correlation coefficient between salinity and distance to irrigation canals in use is 0.9, for instance.

In the study area, the groundwater salinity generally exceeds the salt contents of the river water and that of freshwater used for irrigation. Therefore, infiltration of river water and seepage of freshwater in the irrigation canals should have a dilution effect

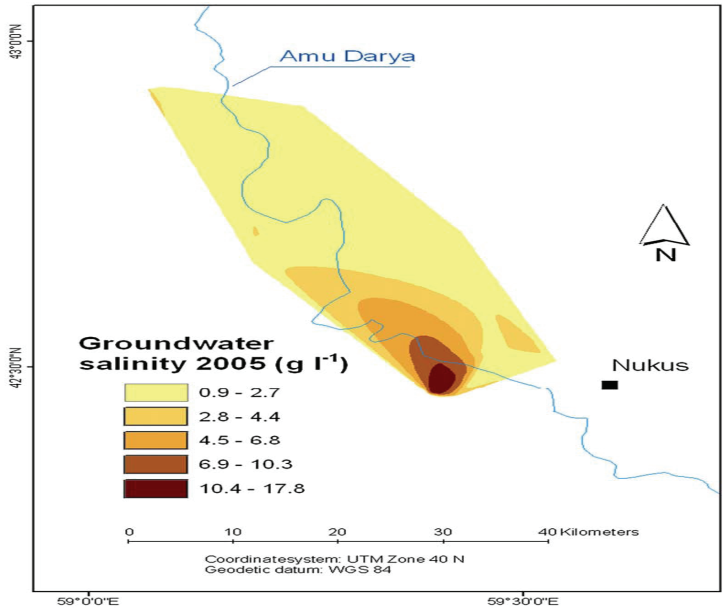


Figure 5. Groundwater salinity above 5m depth of the upper unconfined aquifer, in the irrigated part of the study area, at the start of the growing season (April 2005)

on groundwater composition. In the non-irrigated area where there is no agricultural production, abandoned irrigation canals (considered in Fig. 6b) are still linked with the natural surface water system; some of these canals still receive an inflow of water from the Amudarya. Correlations between the groundwater salinities and the distance to drainage canals and to the terminal freshwater ponds of the wetlands could also be proved (Johansson O., 2008). The interpolated salinities of the groundwater below the wetland reservoirs exceed that of the lower-salinity waters of the wetlands (Mamatov, 2003) by more than 30 g l/1.

However, considering single years only, no correlation between the groundwater salinities and the distances to the Amudarya, or the distances to irrigation canals in use, are detectable for the irrigated area. A possible explanation for the absence of salinity–distance correlations in the irrigated area is that its lower salinity of shallow groundwater makes the salinity contrast between groundwater and surface water too small to be detectable. Three major factors can contribute to the lower salinity of the shallow groundwater in the currently irrigated area. One factor is that the irrigated area is located at a greater distance to the exposed former sea floor of the Aral Sea (as compared with the non-irrigated area; decreasing the exposure to windblown salts (see above discussion of Fig. 5). Besides the direct dilution effect by seepage of freshwater (e.g., O'Hara, 1997; Northey et al., 2006), a main factor is presumably the applied irrigation practice of flooding fields in spring, thereby dissolving soil salt and removing it in a dissolved form via surface water discharge into the Aral Sea or into one of the smaller artificial salt lakes in the region.

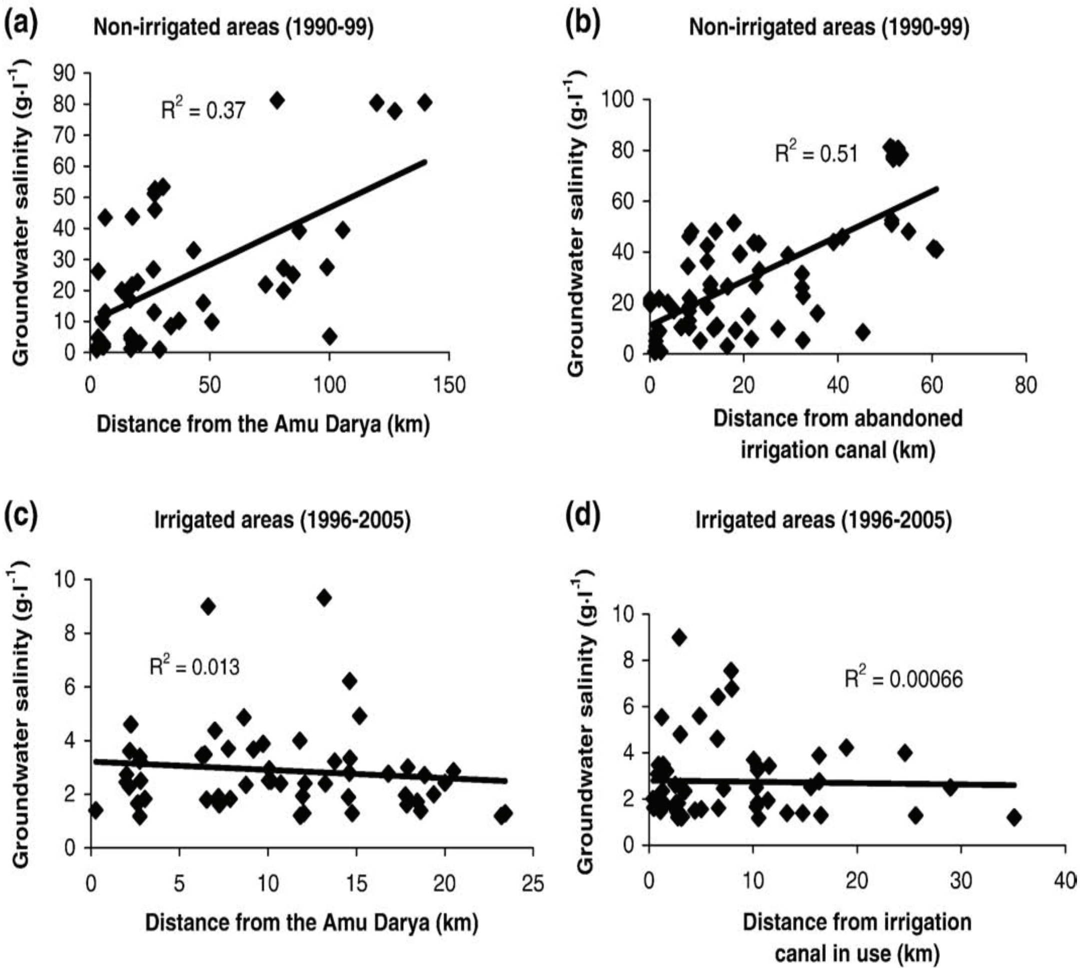


Figure 6. Observed groundwater salinity in measurement wells of the non-irrigated area versus their distance, measured along the groundwater flow direction, from (a) the Amudarya River and (b) abandoned irrigation canals; and in measurement wells of the irrigated area versus their distance, measured along the groundwater flow direction, from (c) the Amudarya River and (d) irrigation canals in use (Johansson, 2008).

The above irrigation practice can sustain shallow groundwater salinities at a relatively low level. If irrigation ceases (e.g. if land has to be abandoned due to water shortage), the salinity of local, shallow groundwater may increase, as observed in this study.However, without externally added irrigation water, soil water flows will decrease at the same time. In the upper part of the aquifer, salinities can get relatively high due to flow stagnation and evapo–concentration of salt, even though salt carried by the irrigation water will no longer be added. A factor that is likely to be important for the shallow groundwater salinity is the vertical transport of salts in the saturated zone, which will be discussed in the following section.

Future possible solutions

Many different solutions to the different problems have been suggested over the years, ranging from feasibility to cost, including the following:

- Improving the quality of irrigation canals;
- Installing desalination plants;
- Charging farmers to use the water from the rivers;
- Using alternative cotton species that require less water;
- Using fewer chemicals on the cotton
- Installing dams to fill the Aral Sea.
- Redirecting water from the Volga, Ob and Irtysh rivers. This would restore the Aral Sea to its former size in 20-30 years at a cost of US$30-50 billion.
- Pump and dilute sea water into the Aral Sea from the Caspian Sea via pipeline.

In January 1994, the countries of Kazakhstan, Uzbekistan, Turkmenistan, and Kyrgyzstan signed a deal to pledge 1% of their budgets to helping the sea recover. By 2006, the World Bank's restoration projects especially in the North Aral were giving rise to some unexpected, tentative relief in what had been an extremely pessimistic picture (Aral Sea from Space, October 2008).

Discussion

Current efforts to mitigate the environmental disaster are worthwhile but small in scale when compared to the total picture. Overall, the situation is likely to deteriorate for the people in the region of the Aral Sea. Water is likely to become scarcer and remain contaminated with microbes, salts and toxic chemicals. More of the seabed will be exposed and more toxic dust will be blown around the region. Stalinization of the soils will continue. In short, their health and wellbeing is likely to erode further as the region further loses its ability to sustain human life. It is clear that the people of the Aral Sea require increased assistance from the rest of the world. While the problems of the Aral Sea have become well known, relatively little has been done to provide practical assistance to those most in need. Perhaps the current conflict and instability in Afghanistan will create greater geopolitical incentives for western countries to assist in Central Asia. Effective assistance in the areas of health and the environment would undoubtedly be much appreciated.

Assistance must be immediate, practical and impact at a local level. Consultation must occur with those who are to be the recipients of aid to ensure that efforts are properly directed. Aid from different sources should be well coordinated to make their activities synergistic rather than competing. Research would best be commenced in conjunction with practical assistance, rather than precede it. The Medecins Sans Frontieres (MSF) approach to operational research should be educative to those who seek to help the people of the Aral Sea area. There is much that could be done to improve the fast decaying health infrastructure in the area.

The effectiveness of Aral Sea Basin organizations responsible for water management, such as the International Fund for Saving the Aral Sea (IFAS), should be supported. Donor nations should work with the appropriate body to ensure interventions are suitable for all stakeholders, roles are clear and the bodies empowered. These bodies should ensure they include stakeholders from the immediate vicinity of the Aral Sea, such as Karakalpakstan. Finding ways to reduce each nation's dependence on cotton production may be a useful objective.

Conclusions

The study area is divided into an upstream irrigated zone and a downstream presently non-irrigated zone that was formerly irrigated to a large extent. The salinity of shallow groundwater is significantly higher in the non-irrigated zone than in the irrigated zone, which illustrates how the salinity of local, shallow groundwater may increase if irrigation ceases.

In the non-irrigated zone, the shallow groundwater salinity is generally much higher than the surface water salinity reported for the same zone by e.g. Mamatov (2003). Near the Amudarya and abandoned irrigation canals the groundwater salinity is lower than the average value for the whole non-irrigated zone. Corresponding trends cannot be found in the irrigated zone.

We observe distinct annual fluctuations in groundwater salinity that are too large to be explained by input from surface water (Amudarya) or wind-blown salt from the dried Aral Sea sediments. Salt transport by groundwater is the only plausible remaining explanation for these changes. With extended groundwater monitoring (increased sampling density and vertical extent), the understanding of the dynamic groundwater and surface water systems can be further improved.

References

1. Alekseeva I., Jarsjö J., Destouni G., and Schrum C., 2008. "Estimation of the Aral Sea water budget and sea–groundwater interactions by a coupled 3D sea–ice–groundwater model". Journal of Marine Systems.
2. Antonov V.N., 2000. Water resources of Uzbekistan, their use in modern conditions and in the future. Collection of scientific articles: Water resources, the Aral problem and environment. Tashkent, "University".
3. Benduhn F., Renard P., 2004. "A dynamic model of the Aral Sea water and salt balance". Journal of Marine Systems 47, 35–50.
4. Bissell Tom, 2002. "Eternal winter: Lessons of the Aral Sea Disaster", (environmental decline of the Aral Sea in Uzbekistan), Harper's Magazine,
5. Ed Ring, 2005. "Siberian Water to Save the Aral Sea", EcoWorld article, http://www.ecoworld.com/features/2005/11/06/siberian-water-to-save-the-aral-sea/,
6. Ecology: The ecological disaster of the Aral Sea, Hemp Info article, 2008. http://www.chanvre-info.ch/info/en/Ecology-The-ecological-disaster-of.html,
7. Glazovsky, N.F., 1995. "The Salt Balance

of the Aral Sea". GeoJournal 35, Kluwer Academic Publishers, Dordrecht, the Netherlands, pp. 35–41.

8. Gilligan Kevin, 2002. Aral history. (The Aral Sea region, Russia), Harper's Magazine,

9. Johansson O., Aimbetov I., Jarsjo J., 2008. "Variation of groundwater salinity in the partially irrigated Amudarya River delta, Uzbekistan", Journal of Marine Systems

10. Johansson O., 2006. "Groundwater and soil salinity changes in the Amudarya delta", Master thesis # N-67, Department of Physical geography and Quaternary geology, Stockholm University, 103 p.

11. Joshua Calder, 1995. „ Aral Sea Loss and Cotton (Aral Case)", http://www1.american.edu/ted/aral.htm ,

12. Mamatov S., 2003. "Study of the groundwater contribution to the Aral Sea region water supply and water quality: strategies for reversibility and pollution control" –INTAS project 1014. EU-INTAS Aral Sea Basin Call 2000, Group CR5 status report of April 30, 2003

13. Michael W., 2002. "Grand Soviet Scheme for Sharing Water in Central Asia is Doundering". The New York Times article, http://www.nytimes.com/2002/12/09/world/grand-soviet-scheme-for-sharing-water-in-central-asia-is-foundering.html?sec=&spon=&pagewanted=all,

14. Micklin P.P., 2008."The Aral Sea Disaster", Annual Review of Earth and Planetary Sciences 35 (4): pp.47–72. doi:10.1146/annurev.earth.35.031306.140120.

15. Micklin P.P., 2004. "The Aral Sea crisis". Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 99-123.

16. Normatov I., 2004. Academy of Sciences, Institute of Water problems, Hydropower & Ecology (TJ). "Water balance and solution of water problems in the Aral Sea basin".

17. Northey, J.E., Christen, E.W., Ayars, J.E., Jankowski, J., 2006. Occurrence and messirement of salinity stratification in shallow groundwater in the Murrumbidgee Irrigation Area, south-easteren Australia. Agricultural Water Manegement 81, 23-40

18. Natalya Antelava, 2007. "Kazakhs get loan to save Aral Sea" BBC News, Aral Sea, http://news.bbc.co.uk/2/hi/asia-pacific/6538073.stm

19. O'Hara, S.L., 1997. Irrigation and land degradation: implications for agriculture in Turkmenistan, Central Asia. Journal of Arid Environments 37, pp 165-179

20. Kazakhstan Government and World Bank Project for Saving Aral Sea, 2006. http://www.worldbank.org.kz/external/projects/main?pagePK=64283627&piPK=73230&theSitePK=361869&menuPK=361902&Projectid=P046045

21. "Rebirth" Island Joins the Mainland, 2001. Earth Observatory article, http://earthobservatory.nasa.gov/IOTD/view.php?id=1706

22. UNDP (United Nations Development Program) (2007): Water – Critical

Resource for Uzbekistan's future. UNDP Tashkent, pp. 38–60.

23. Water related vision for the Aral sea basin for the year 2025, UNESCO, 2000, 237p.

98 年 05 月 13 日收稿
98 年 06 月 01 日修改
98 年 06 月 10 日接受