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Salinization of River Waters and Suitability of Electric Conductivity Value for Saving Freshwater from Salts in Aral Sea Basin

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Abstract: The dynamics of water salinization (WS) and its relationship with electric conductivity (EC, µS/cm), the suitability of EC for saving freshwater from salts as well as ionic composition in the main rivers of the Aral Sea Basin (ASB), Amudarya, Syrdarya and Chirchiq were analyzed. Preliminary results reveal that there are strong linear relationships between salinity and EC with r^2 values 0.84-0.99. Thus EC value can be recommended as suitable criterion for assessing freshwater pollution with salts. The water quality standard of 1000 mg/L in ASB corresponds to an EC value of 1330-1930 µS/cm depending on the ionic proportions in the specific river basin. Currently, in waterbodies of middle and lower reaches of Amudarya and Syrdarya Rivers, sulphates are the leading anions followed by chlorides in the Amudarya and bicarbonates in the Syrdarya River. The most abundant cations are sodium in case of Amudarya and calcium in case of Syrdarya.

Key words: Salinization, electric conductivity, river waters, ionic composition.

Introduction

Re-introduction of water from irrigated fields and discharge of industrial effluent is a common cause of salinization of surface waters in the Aral Sea Basin (ASB) with negative effect on aquatic ecosystems and human health, mostly in lower reaches of rivers. Salinity in Aral Sea rose from 10 g/L in 1960 to more than 130 g/L in 2010 and more than 150 in 2015 and 200 was predicted for 2021 (Gaybullaev et al., 2012). Aral Sea fishery flourished in first half of the last century and until 1965 has started to diminish sharply after 1970s and ceased in 1983 above all due to critical high salinity and disappearance of fattening and spawning places (Micklin, 2007; Karimov, Keyser, 1998; Aladin et al., 2017; Micklin et al., 2014).

Climate change will likely increase water scarcity. In most desert and arid parts of the Aral Sea Basin air temperature has increased by 2.8°C during the 20th century. IPCC (2007) predicts an increase in annual mean air temperature of 3.7°C by 2100—higher than global average (2.8°C)—and a decrease of precipitation. Declining freshwater discharge due to glacier melting and increasing evaporation exacerbated acute water scarcity in the Aral Sea Basin.

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Average long-term annual volume of drainage waters has varied between 28.0 km^3 and 33.5 km^3. More than 55% returns to rivers and about 30% ends up in natural depressions, from which the water evaporates. Before the 1960's 21 million t/y of salt were introduced to the arid areas in Central Asia. Currently only within the entire Amudarya river basin annually more than 100 million t/y of salts are diverted to rivers and natural depressions causing salinization of downstream lands, waters and peripheral lakes of anthropogenic origin (Nasonov and Abirov [cited 2018]).

The objective of the present work was to analyze dynamics of water salinization (WS) and its relationship with electric conductivity (EC, μS/cm), suitability of EC value for saving freshwater from salts, as well as ionic composition in the main rivers Amudarya and Syrdarya of the ASB as well as Chirchiq River.

Study Site and Data Compilation

The Aral Sea Basin with the Amudarya catchment of 309,000 km^2 and the Syrdarya catchment of 219,000 km^2 are home of approximately 70 million people. These catchments have 100-200 mm/y precipitation with: 30-50% in spring, 25-40% in winter, 10-20% in autumn and 1-6% in summer.

More than 90% of water is being used for irrigation in cotton monoculture, causing total water runoff reduction to the Amudarya and Syrdarya river deltas from 56 km^3 to 5 km^3, in some years it is even nearly ceased.

One site in upper and another in lower sections of each river were selected for data compilation, namely: near City Termez in upper and City Nukus in lower (200 km to the delta) for Amudarya River; near City Namangan in upper and after inflow of collector GPK in midstream of Syrdarya River; and near City Chirchiq in upper and Village Chinaz in lower reach for Chirchiq River (Figure 1).

Data on long-term water salinity (WS) and electric conductivity (EC) changes were obtained from: State Hydrometeorological Service of Uzbekistan for 2005-2014 and the literature (Rubinova, 1985, 1987). YSI Professional plus Instrument was used for field measurements in upper and lower reaches of Chirchiq River during the vegetation period of 2011.

Results

Trends in River Water Salinity

There was no trend in salinity levels of Amudarya and Syrdarya rivers between 1913 (when measurements

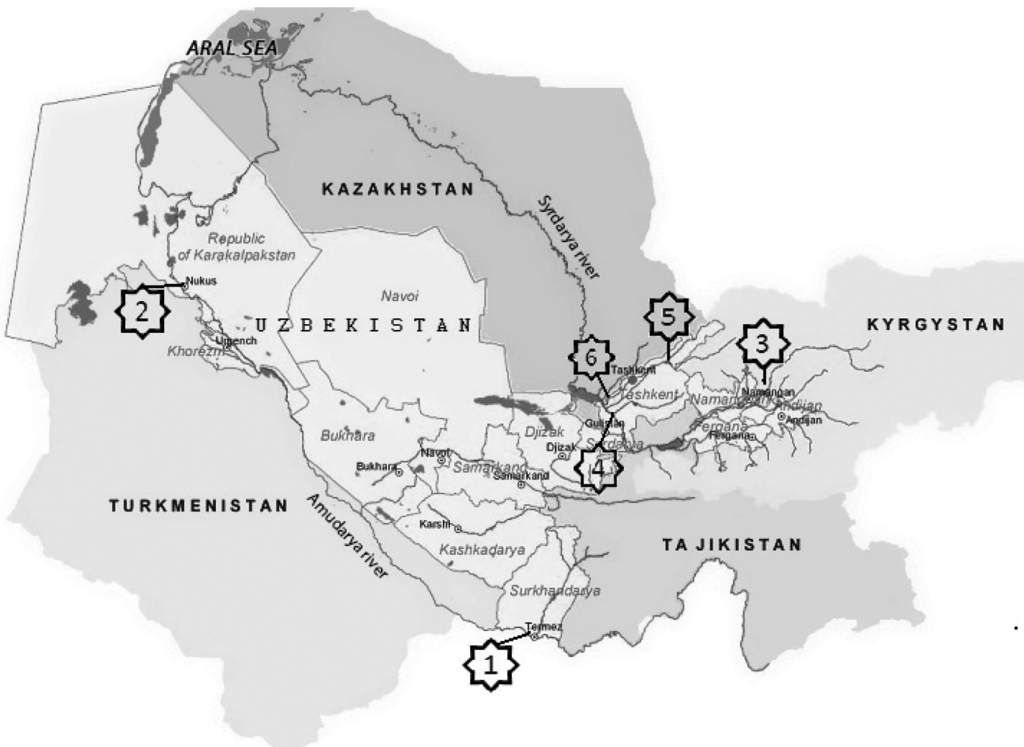

Figure 1: Map of ASB region with study sites. 1 – Amudarya river upstream, near city Termez; 2 – Amudarya river downstream, city Nukus; 3 – Syrdarya river upstream near city Namangan; 4 – Syrdarya river midstream after inflow of collector GPK; 5 – Chirchiq river upstream near city Chirchiq; 6 – Chirchiq river downstream near village Chinaz.

began) and the 1960s and average annual salinity levels were between 420 and 620 mg/L (Rubinova, 1987). In the 1960s, salinity started to rise reaching 920-1310 mg/L between 2005 and 2014 (average annual values) (Figure 2).

Before the 1980s in upper and middle reaches of Amudarya and Syrdarya the total salinity usually did not exceed 500 mg/L between May-October and 800 mg/L between November-April (Rubinova, 1985, 1987). However, during the period of 2005-2014 these values increased up to 800 and 1600 mg/L respectively.

In Chirchiq river during the vegetation period of 2011 average water salinities in upstream and downstream were 132 (90-200) and 597 (470-720) mg/L, respectively.

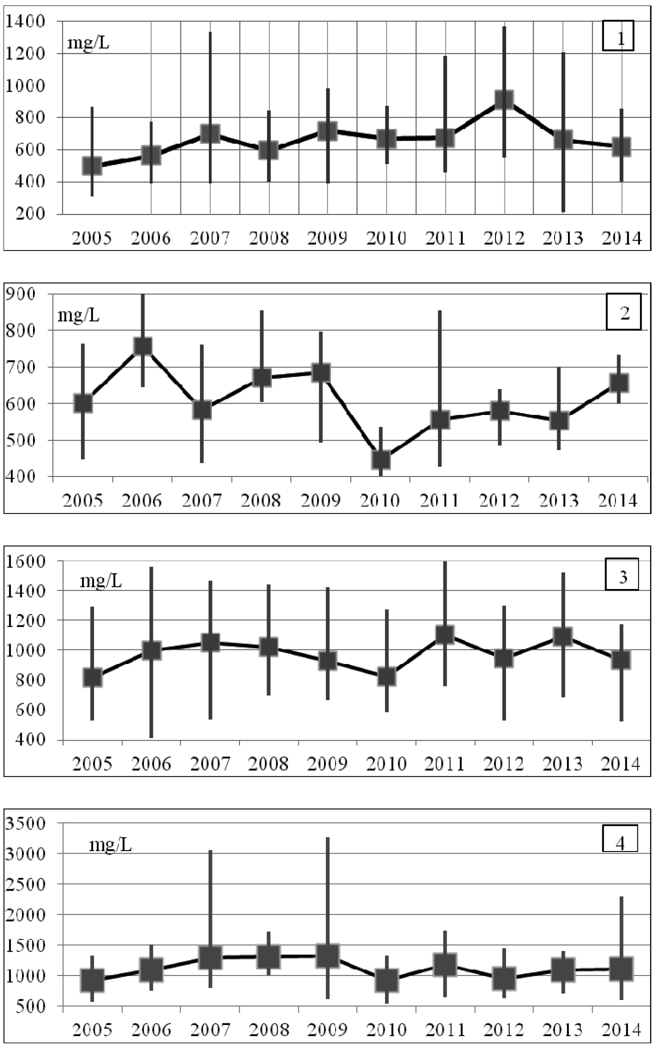

Figure 2: Dynamics of annual average (min – max) water salinity in rivers: 1 – upstream Amudarya river; 2 – upstream Syrdarya river; 3 – midstream Syrdarya river; 4 – downstream Amudarya river.

Salinity-EC Relationships

Strong linear relationships were found between salinity and EC expressed as r^2 values; for Amudarya river: 0.88-0.99 in upper reach and 0.91-0.99 in lower reach; for Syrdarya river: 0.84-0.99 in upper reach and 0.73-0.98 in middle reach; and for Chirchiq river 0.99 in upper reach and 0.96 in lower reach. Mean values of salinity and EC for the study period (2005-2014) were 660 mg/L and 926 µS/cm for the upper Amudarya reach and 1120 mg/L and 1644 µS/cm for the lower Amudarya reach; 610 mg/L and 925 µS/cm for Syrdarya upper reach and 970 mg/L and 1289 µS/cm for Syrdarya middle reach (Figure 3) and for the Chirchiq river 132 mg/L and 222 µS/cm in upper reach and 597 mg/L and 1152 µS/cm for the vegetation period of 2011.

Thus, in Amudarya 1 mg of salinity was equal to 1.40 µS/cm in the upper reach which was somewhat higher than in the lower reach 1.47 µS/cm. The similar tendency was observed also for the Chirchiq River: 1 mg of salinity was equal to 1.68 µS/cm in upper reach and 1.93 µS/cm in lower reach. However, opposite picture was observed in Syrdarya River: 1 mg of salinity was equal to 1.52 and 1.33 µS/cm in the upper and middle

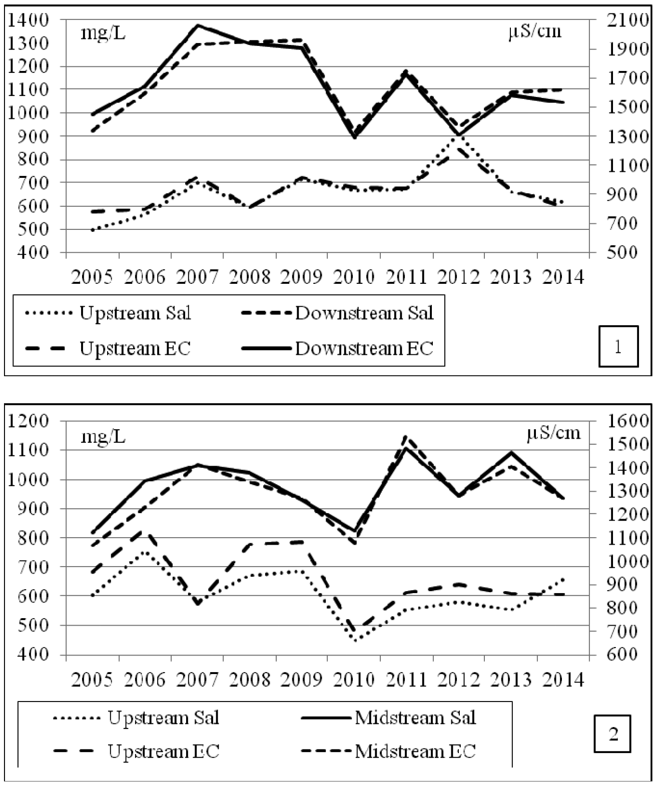

Figure 3: Relationships between water salinity (Sal) and EC: 1 – along the Amudarya river; 2 – along the Syrdarya river.

reaches, respectively. This is most likely explained by considerable variations in ionic composition of water.

Preliminary results reveal that the water quality standard of 1000 mg/L in ASB basin will be reached when EC equals to 1.330-1.930 μS/cm depending on the river basin.

Trends in Ionic Composition

There was no trend in water ionic proportions along the Amudarya and Syrdarya rivers between 1913 and the 1960s where the dominant anions and cations in Amudarya river were sulphate, bicarbonate, calcium and sodium. In case of Syrdarya river the order of leading anions is changing: bicarbonate, sulphate, calcium and sodium.

However, now in lower reach of Amudarya River (Nukus 200 km to the delta) chlorides became the second dominating anions, associated mainly with sodium. While now in the Syrdarya River sulphates became the dominating anions instead of bicarbonates, again with leading cation sodium (Figure 4).

The increase of mineralization caused by diversion of agricultural return waters has led to rising of concentrations of more toxic ions: magnesium, sodium, chlorides and sulphates.

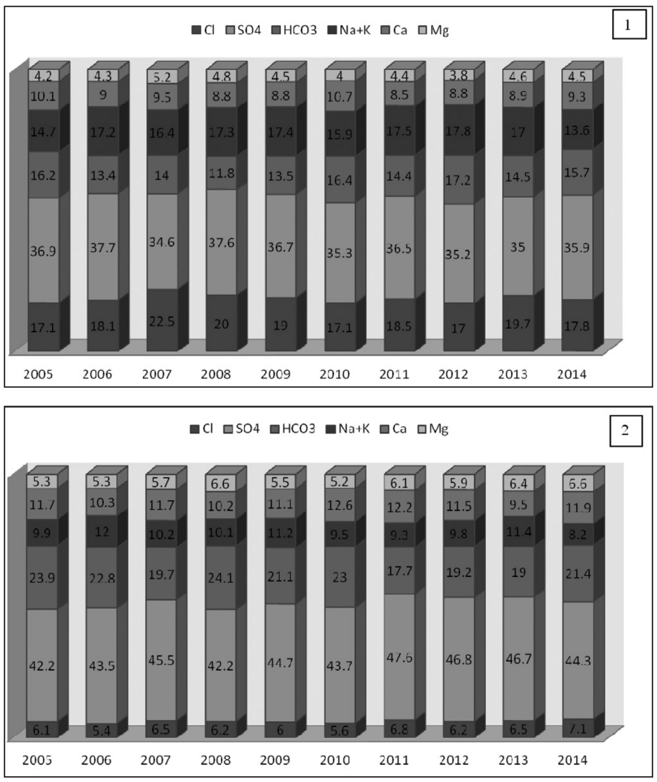

Figure 4: Ionic composition (%) of water: 1 – downstream Amudarya river; 2 – midstream Syrdarya river.

Discussion

High salinity levels in water may have numerous adverse effects on ecosystem biodiversity and on human health, when unpurified water is used for drinking (Cañedo-Argüelles et al., 2016). The threats from freshwater salinization can extend over large areas. For example, Australia's National Land and Water Resources Audit of 2000 reported that 11,800 km of streams and lake perimeters were at high risk from salinization in Western Australia with ion mixtures similar to seawater (NLWRA, 2000). In Uzbekistan, increased water salinization in excess of 1000 mg/L is a common situation downstreams as well as in some periods also in middle reaches of most rivers, which makes water unsuitable for drinking. Water pollution problems might lead to severe local and transboundary upstream-downstream water conflicts in Zarafshan river basin (former tributary of Amudarya River) within the next decades (Groll et al., 2013). More than 15 large manmade brackish water residual lakes (3–12 g/L) with 9000 km^3 of total water surface area are fed by high salinized collector-drainage waters in Uzbekistan (Karimov et al., 2014).

In ASB countries including Uzbekistan, maximum permissible levels of water pollution with mineral salts is controlled by total mineralization measured as the sum of all dissolved salt ions. EC is measured only for analytical purposes and not for control. In most European countries as well as in USA, Australia and other countries, EC value is widely used for total water salinity control and EC higher than 2000 μS/cm are also acceptable for drinking water and irrigation (Cañedo-Argüelles et al., 2013).

Many water salinity quality standards for human consumptions around the world, including the ASB region, are set at 1000 mg/L (total ions content). Canada and the United States are the only countries in the world that identify concentrations of a specific ion (chloride) above which freshwater life will be harmed (U.S. EPA, 2002; CCME, 1999). However, proportions of other ions (e.g. Mg^{2+}, HCO_3^-) remain free from regulation in spite of their potential toxicity (Van Dam et al., 2010). Cañedo-Argüelles et al. (2016) argue that salinity standards for specific ions and ion mixtures, not just for total salinity, should be developed and legally enforced to protect aquatic life and ecosystem services.

Downstream of most rivers of ASB the levels of salinization exceeding the threshold level of 1000 mg/L were reached in the beginning of 1980s due to re-introduction of agricultural return waters from irrigated fields. During the last decade the average annual water salinity in Amudarya downstream changed between 916 and 1,313 mg/L and in Syrdarya River between 819 and 1,107 mg/L. This is characteristic also to other rivers on their plain reaches, e.g. in 2002-2010 in lower Zarafshan river water salinity exceeded 1000 mg/L in comparison to less than 300 mg/L in upper reach (Groll et al., 2013). The situation obviously will get worse in the future due to predicted reduction of discharge of the ASB rivers by up to 50% in 2050 caused by global warming (Agaltseva, 2008), which will reduce the capacity of surface waters to dilute salts from agricultural drainage return waters.

Conclusions

Based on conducted research following conclusions are made: (1) Preliminary results reveal that there are strong linear relationships between salinity and EC with r^2 values 0.84-0.99. Thus EC value can be recommended as a suitable criterion for preventing freshwater from pollution with salts. (2) The water quality standard of 1000 mg/L in the Aral Sea basin corresponds to an EC value of 1330-1930 µS/cm depending on the ionic proportions in the specific river basin. (3) Currently, in waterbodies of middle and lower reaches of Amudarya and Syrdarya rivers, sulphates are the leading anions followed by chlorides (Amudarya) and bicarbonates in the Syrdarya river. The most abundant cations are sodium in case of Amudarya and calcium in case of Syrdarya.

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