CZECH UNIVERSITY OF LIFE SCIENCES IN PRAGUE

Faculty of Tropical AgriSciences

Department of Sustainable Technologies

Quality of Drinking and Irrigation Water in Aral Sea Region

Diploma Thesis

Thesis supervizor: doc. Ing. Vladimír Krepl, CSc.

Author: Bc. Václav Placák

Prague 2013

Prohlášení

Prohlašuji, že jsem předloženou diplomovou práci na téma Kvality pitné a závlahové vody v oblasti Aralského jezera vypracoval samostatně a s použitím dále uvedených informačních zdrojů.

V Praze, dne 21. srpna, 2013 ....

Václav Placák

Declaration

I hereby declare the diploma thesis titled ‘Quality of Drinking and Irrigation Water in the Aral Sea Region’ is work of my own and with using of information sources mentioned in the text.

In Prague, 2013 August, 21 ....

Václav Placák

Poděkování

Za odborné vedení a pomoc při tvorbě této diplomové práce bych chtěl poděkovat vedoucímu diplomové práce doc. Ing. Vladimíru Kreplovi, CSc. Poskytl mi cenné rady i informace a umožnil mi práci napsat.

Můj velký dík patří také Ing. Zbyňku Klose za inspiraci ke zpracování práce, Ing. Anně Placákové a Bc. Milanu Drahošovi, kteří mi poskytli cenné rady při zpracování statistických i dalších údajů v mé práci obsažených.

Acknowlegment

For professional leadership and help with diploma thesis creation I want to give thanks to the supervisor of my diploma thesis doc. Ing. Vladimír Krepl, CSc. He gave me valuable advice and information also which enabled me to write this work.

My great thanks belong also to Ing. Zbyněk Klose for inspiration about thesis arrange, Ing. Anna Placáková and Bc. Milan Drahoš who gave me valuable advice for the statistical and other data analyses included.

Abstract

The Aral Sea is one of the most environmental endangered regions in the world. The situation there is very critical in many aspects, environmental, ecological, economic and social.

There are many reasons for the environmental disaster in the Aral Sea region,, but the starting point was the initiation of the massive agriculture use of land in this area during the Soviet era in last century. At this time the two main sources of water for Aral Sea; Amu-Darya and Syr-Darya rivers were diverted for irrigation purposes. This caused a decrease of water inflow from these rivers and along with the decrease of water inflow from the Pamir glacier melt also decreased the volume of water in the Aral Sea. This process started in 1960.

Because of the water volume decrease the salinity of the water in the sea also started rise. This effect was multiplied by the fact that the water does not flow away from the sea and that only clean water evaporated. Salt therefore accumulated there.

The objectives of this thesis are to show the decrease of the Aral Sea water surface ilustratively by maps and to show the correlation between the main phenomena of water quantity and quality. This data can be used for the prediction of the future of the Aral Sea with regard to the special components of salinity.

GIS, Project R, Scilab, Microsoft Excel, PCA analysis and Linear Regression were used to achieve these objectives.

In this work demonstrates the reduction of water surface area from 1973 to 2013 with maps showing the permanent water area and also the strong correlation between the main phenomena is proved. The development of the total water salinity and salinity components till 2048 has been estimated from this data by statistical methods.

Increased salinity level makes the quality of water worse. These new water conditions started to become unacceptable for original water biota living there. This ecosystem died.

This situation needs to be resolved immediately. These conditions need to be improve because without this the Aral Sea ecosystem, climate and economical conditions will significantly change.

Key words

Aral Sea, Environmental disaster, Glacier, Glacier meltdown, Pamir Mountains, Salinity

Abstrakt

Aralské jezero je jedno z míst na světě, které je vysoce ohroženo environmentální katastrofou. Situace je velmi kritická z několika hledisek, a to jak z environmentálního, tak ekologického, ekonomického a také sociálního.

Environmentální katasrofa v regionu Aralského jezera má několik důvodů, ale počáteční příčinou byl začátek masivního rozvoje zemědělství v této oblasti během vlády Sovětského svazu. Během tohoto období byly odkloněny dvě řeky, hlavní zdroje vody pro Aralské jezero; Amudarya a Syrdarya pro zavlažovací účely. To zapříčinilo pokles přítoku vody z těchto řek a společně s málo známým úbytkem vody v Pamírských ledovcích způsobilo pokles objemu vody v Aralském jezeře. Tento proces začal v roce 1960.

Protože klesá objem vody, začala v jezeře stoupat salinita. Tento efekt násobí také fakt, že voda se solí z jezera neodtéká a odpařuje se jen čistá voda. Sůl se tak v jezeře kumuluje.

Cílem této práce je ukázat ústup rozlohy hladiny Aralského jezera ilustrativně pomocí map, ukázat korelaci mezi hlavními fenomény kvantity a kvality vody a tato data použít pro odhad budoucí salinity Aralského jezera s ohledem na hlavní prvky které tvoří celkovou salinitu.

K naplnění těchto cílů byly použity programy GIS, Project R, Scilab, Microsoft Excel, Analýza hlavních komponent a Lineární regrese.

V této práci je ukázané zmenšení rozlohy hladiny Aralského jezera od roku 1973 do roku 2013 pomocí map, ukázaná stále zavodněná oblast a také ukázaná silná korelace mezi hlavními fenomény. Z těchto dat je statistickými metodami odhadnutý vývoj celkové salinity a prvků salinity Aralského jezera do roku 2048.

Vzrůstající úroveň salinity zhoršuje kvalitu vody. Tyto nové vodní podmínky začínají být neakceptovatelné pro původní biota, která zde žijí. Ekosystém umírá.

Tato situace potřebuje okamžité řešení. Tyto podmínky potřebují upravit, protože bez toho by to znamenalo konec ekosystému Aralského jezera, klimatických i ekonomických podmínek.

Klíčová slova

Aralské jezero, Environmentální katastrofa, Ledovec, Tání ledovců, Pamírské pohoří, Salinita

Content

List of Abreviations

GDMC.. Geo-Database Management Center

GIS... Geographic Information System

ICWC .... Interstate Commission for Water Coordination

NASA.. National Aeronautics and Space Administration

PCA... Principal Componentes Analysis

SI.............................. International System of Units (Le Système international d'unités)

UNEP.. United Nations Environment Programme

UNESCO...................United Nation Educational, Scientific and Cultural Organization

WHO... World Health Organization

List of Equations

List of Figures

1 Introduction

The Aral Sea region is an area with many natural and cultural problems. For a better understanding of the problems in this region it is useful to know something about its history and geographic location.

1.1 Geographic Location

The Aral Sea, is a lake located in central Asia in the Turan lowlands between Uzbekistan on the south and Kazachstan on the north. Namely among Adobe and Kyzyrolda, which are Kazachstan provencies and Uzbekistan autonomous region Karakalpakstan (Bissell, 2008; Micklin, 2007), see fig. 1.

Till year 1973 the Aral Sea was the fourth largest inland water body in the World, with a lake surface of almost 68, 000 square kilometres (Bissell, 2008; Micklin, 2007; Benduhn and Renard, 2004).

In these days it is one of the regions with substancial water problems, whose solution was impossible without international scientific intervention (UNESCO, 2009).

1.2 Climate and Hydrology

The climate in this area is characterized as an inland desert, with a wide ranging air temperature. There is a very hot summer folowed by acold winter, with little rain. Rainfall is only 100 milimetres per year, which is a small fraction of lake evaporation (Bissell, 2008).

Major sources of water flow into the Aral Sea are rivers, namely Amu-Darya and Syr-Darya (Micklin, 2007; Haag, 2010).

1.2.1 Amu-Darya

Amu-Darya is the major river in central Asia and also the main source of Aral Sea water (Rakhmatullaev et al., 2009). 68% the water in the lake is from the Amu-Darya catchment area (UNEP, 2006). T^he river flows through Afghanistan, Tajikistan, Turkmenistan and Uzbekistan and is created by influence of main rivers; Vakhsh and Panj.

Next tributaries are Surkhan Darya, Sherabad and Zeravhsan river. In ancient history the river served as the borde between Ariana and Turan (Rakhmatullaev et al., 2009), see fig. 2, 3.

The Panj river is the main tributary of the Amu-Darya (Haag et al., 2007) and the water mainly originates from The Pamir Mountains in Tajikistan, the primary source being the Zorkul .lake. The river comes from the Allay Valey in the Pamir Mountains also (Rakhmatullaev et al., 2009), see fig. 4. This means that 90% of the total year water discharge (90% from 78 km^3) comes from glacier water (UNEP, 2006).

In the years 1939-1949 data collected confirmed that the river flow was strongly dependant on water from glacier in context of seasonal meltdown (Haag, 2006).

Total lenght is 2, 400 km, basin is 534, 739 km^2, average water discharge is 2, 525 m^3s^{-1} (Rakhmatullaev et al., 2009). Most of the water lost in the arid zones around river flow is by evaporation and mainly because of artificial use, about 4 mil. km^2 of land is irrigated, see next (ICWC, 2010).

1.2.2 Syr-Darya

The river flows through Kyrgyzstan, Uzbekistan, Tajikistan and Kazakhstan. The Syr-Daria river comes from the Thian Shan mountains in Kyrgyzstan and the eastern part of Uzbekistan. It means two parts, namely rivers Naryn and Kara-Darya create the Syr-Darya river (Viviroli and Weingartner, 2004).

The main tributaries of the river are Chirciq, Arys, Chu and Sarysu. River length is 2, 212 km and water basin about 402, 760 km^2. Average water discharge is 1, 180 m^3s^{-1}, half that of the river Amu-Darya (Viviroli and Weingartner, 2004; Rakhmatullaev et al., 2009), see fig. 4. This fact makes Amu-Darya more important in Aral Sea water supply.

1.2.3 Original Source of Water

In montaineus rocky regions like the Aral Sea region the typical source of water is glaciers. Ice melt provides water to rivers and is influenced by seasonal temperature difference (Johannesson et al., 1989). When the mass of glacier and seasonal temperatures are changed, then the amount of water in rivers is also changed (Johannesson et al., 1989;

Lambrecht et al., 2010). After the complete meltdown of glacier water the reivers are dependant on seasonal snow and ice cover only (Barnett et al., 2005).

This meltdown-amount of water proportion effect is very important for the water supply of rivers which do not have other sources of water. Typicaly rivers in arid regions, like Amu-Darya, which is one of the rivers in the world with highest share of mountain discharge, more than 90% (Viviroli and Weingartner, 2004). It is defined like a portion of river total runoff which is situated in a mountaneus catchment part.

(Namely 80% water in Amu-Darya flow is from glacier melt originaly (Froebrich and Kayumov, 2004), which means this river is strongly dependent on glacial resources, especially the volume of water rather than the quality of water

The quality of water from glacier meltdown is constant. We can predict clearness of this water, with one exception. This is defined as acid shock which is the water polution from upper layer of glacier (snow and ice) which accumulate during the winter period and which is released during the warmer summer period. Even then the number of pollutants is not significant to in the quality of water and we can neglect it.

In this interpretation we can presume a very high quality of glacier water and based on this, that all sources of pollution (salts, heavy metals, pesticides, herbicides or other chemicals, etc.) gets into the water during river flow. Mainly from anthropogenic activity in lowlands around Aral Sea (see next).

From these facts we can assume the only way the amount of water from glaciers can affect salinity in the Aral Sea is in the volume of water released from glaciers into the river flows during the years. First idea is simply; we can show this fact on basic equation:

[1] $$c = {}^{m}/_{V}$$

Where $\boldsymbol{c}$ is the concentration of salts [$^{g}/_{l}$], $\boldsymbol{m}$ is the mass of salts [g] and $\boldsymbol{V}$ is the volume of water [l] (Kameníček, 2009).

The majority of research done and studies about the quality of Aral Sea water calculate with stable water volume from glacier melt, but the glaciers in Pamir are constantly melting and getting smaler. It signifies also that there is less water from ice in the river flow.

In the moment when ice take of, the only source of water will be seasonal snow cover and this is not enough (Haag et al., 2004; Haag et al. 2011).

1.3 Aral Sea is changing over Time

The sea surface is changing over approximately fifty years. After year 1960 the area of the lake started getting smaller and today is only 10% of sea surface previously. (Bissell, 2008; Huss et al., 2010). Aral Sea has lost 90% of its volume over the years 1960-2006 (Micklin, 2007). See figs. 5 and 6.

In the year 1960 the surface of sea was 53 meters above sea water level and approximately 68, 000 km^2. The greatest south to east dimension was 435 km and east to west was 290 km. The average water depth was 16 m and maximum deep was 69 m (Bissell, 2008).

From this year the water level and sea surface dramatically declined,because of the diverting of the Amu-Darya and Syr-Darya rivers for agricultural purposes, as sources for irrigation (Huss et al., 2010).

This step corresponded with the Soviet agricultural plan included rice, cereals and cotton growing in the Aral Sea region. This plan was especially based on cotton cultivation for export purposes. One of the many consequences is that Uzbekistan is today the largest cotton exporter in the world but also the country facing one of greatest environmental disaster in world (Micklin, 2007).

Construction of irrigation canal system started in the 1940's, but many of it was poorly built. For example in the largest canal, known as the Quaraqum canal, there was 30-75% loss of water by evaporation and seepage. Today only approximetely 12% of canals are adequately waterproofed (Akhtar et al., 2008).

In total almost 47, 750 km of inland irrigation canals were built but only 30% have anti filtration linings and only 77% of farms have flow gauges. This situatiton signified that between 30-60 km^3 of water flows and losses in canals and farms and Sea water is shorter by this quantity. In the year 1960 the Aral Sea started to significantly shrink (Micklin, 2007).

Starting in this year the water level of Sea fell every year by over 20 cm on average, in the year it was 50-60 cm and from the year 1980 it is circa 80-90 cm. This phenomenon can be explained by the relationhip between water surface area and volume of water which is lost, in addition to the increasing use of irrigation water. Cotton production in the years 1960 till 2000 paradoxicaly doubled (Huss et al., 2010).

1987 was the year, when the Aral Sea was divided into two parts, due to the lack of water. The newly formed parts are called North Aral (smaller part) and South Aral (biger one) (Akhtar et al., 2008).

In the year 2003 the amount of water getting to the lake rapidly felln, the South Aral Sea became divided into the Western and Eastern basins and in 2004 the surface area was only 17, 160 km^2 (Micklin, 2007; Huss et al., 2010).

Only 10% of original size reached the sea in 2007 and salinity increase by approximately 100 $^{g}/_{l}$ (salinity of average sea water is commonly 35 $^{g}/_{l}$!) (Micklin, 2007).

1.4 Environmental Disaster

The described retreat of the water level of the Aral Sea was not any surprise in the Soviet Union. Alexander Asarin, the Russian hydrologist pointed to this in the 1964, but the irrigation project was part of a five year plan, so it was fully approved by the Soviet goverment (Micklin, 2007). The irrigation system built in Soviet era was old and inefficient from the begining (Glantz, 2005).

During the years 1960 -l 1980 some projects of how to divert the Ob and possibly the Irtysch rivers were created (see fig. 7) to supply central Asia and the Aral Sea by water, but it was not realized for economic and environmental reasons (Létolle and Mainguet, 1996).

During the period 1960 - 2000 the Sea surface shrank by over 60% and now the water area is 28, 687 km^2 compared to the original 68, 000 km^2. As a result of increase water volume salinity also increase from 10 $^{g}/_{l}$ to 45 $^{g}/_{l}$ (on average) (Micklin, 2007). The rising salinity was also contributed to by the fact, that crops, mainly cotton, were grown as monocultures, without any attempt at crop rotation. The high concentration of pesticides, herbicides and rudiments of fertilizers in sthe oil together with the reduction of essential nutrients created almost unusable land.

Runoffs of massive amount of pollutants from the land into the Sea water gave rise to the higher salinity of the Sea water. Combined with the low inflow from water sources causes little mixing of water in the lake and the aalinity at the bottom is higher than at the top (Akhtar et al., 2008; Aladin et al., 2009).

The facts introduced above show, that conditions created in Sea water were unacceptable for the majority of fauna and flora lake ecosystems (Micklin, 2007).

The lack of fresh water also impacted on the people who live there. For example, the high incidence of lung diseases (Tuberculosis, Pneumonia, Pneumokoniosis, etc.), cancer, anaemia, and higher risk of infection from diseases are common in this region. The dust in the environment also causes liver (cirrhosis), kidney (toxic nephritis) and eye (keratoconjuctivitis) diseases (Povýšil et al., 2007).

In this way the increased environment risks and incidence of health disability especialy affect vulnerable part of population, namely children and old people. Child mortality rate is 75 per 1, 000 living newborns and maternity death 12 per 1, 000 women (Aladin et al., 2009; Povýšil et al., 2007).

The high concenration of minerals and other polutants damage local plants and their higher concentration in the athmosphere causes the large diference in temperatures (very hot summer and cold winter) (Aladin et al., 2009; Benduhn and Renard, 2004).

The fact which makes the situation more critical is the growing demand for water. This situation needs an interdisciplinary approach to sustainable land use and the future use of water (Martius et al., 2009).

These extreme environmental conditions make this region very interesting for water balance studies. Many authors work in lower part Amu-Darya basin, where water is mainly used for agricultural-irrigation purposes (Conrad et al., 2007; Bekchanov et al., 2010).

1.5 Aral Sea Ecology

When increasing salinity began the original biota died. For example species like *Calanipeda aquaedulcis, a* formerly dominant biota died out.

From year 2002 only *Platichthys flesus luscus* and *Atherina boyeri caspia*survived in small lakes around the former Aral Sea (Mirabdullayev et al., 2004).

2 Objectives of Thesis

The Aral Sea is a well-known region all over the world that today is in a very bad situation as a consequence of an environmental disaster. The environmental, social and economic conditions have been studied by many authors and thanks to them today we have a great amount of data about the situation there.

The objectives of the thesis are through the mat-statistics and GIS methods to prove the hypothesis about the Aral Sea surface reduction, the correlation between main phenomena of Aral Sea water and the prediction of future of the Aral Sea water quality.

In this thesis will be shown:

a) the **decline of Aral Sea surface area**. This decline will be shown graphicaly and by a number in maps made by the GIS programme.

b) the **correlation between the main phenomena of the amount of Aral sea water,** namely suface area and depth, water volume, river inflow and salinity. These phenomena come out from data measured by international scientific teams and also data measured in GIS programme which was calculated for this thesis will be used.

c) very interesting is also the prediction of the future situation, especialy in comparison with *status presens*. In this work there will be **schema of the possible future situation of Aral sea water quality**, especialy salinity; salinity included disolved minerals, ions, heavy metals, fertilizers, pesticides, herbicides, etc. measured in International System of Units (*in original form Le Système international d'unités*, SI) units $^{g}/_{l}$. In this thesis possible total salinity and constistuents of salinity evolution in the future will be shown.

3 Salinity

Salinity is defined as the measure of salts disolved in water. It suppose solubility of compounds in water, it means compounds have to be hydrophilic. In another way hydrophobic substances are not solubile in water and make sediments at the bottom.

Salinity is usualy measured as parts per thousand [‰], which corelate with $^{g}/_{l}$ units which are used more often and ilustrative.

On average sea water salinity is approximately 35 $^{g}/_{l}$ or 35 ppt. This signifies that in every 1000 g of seawater 35 g of salts are included (Kameníček, 2009).

Compounds which we call salt are mixtures of ions, minerals, etc. Most often they include sodium (Na^{+}) and chlorine (Cl^{-}). These make well known compounds like sodium chloride (simply kitchen salt) which is 85. 7% of disolved salts. The next components are calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}) and sulphate (SO^{4-}). In Aral sea water there are also special substances precipitated there associated with the specific water regime there (see below). These are mainly calcium carbonate ($CaCO_3$), gypsum ($CaSO_4 \cdot 2H_20$), mirabilite ($Na_2SO_4 \cdot 10H_2O$) and epsomite ($MgS0_4 \cdot 7H_20$) (Létolle and Mainguet, 1996; URI, 2001).

Salinity can be measured in a few ways, but is most often measured by the electric conductivity of water. Simply, it can be said that the more salt disolved in the water (it mean high salinity) the better the electric conductivity of water is. We compare measured water with water with known salinity as a reference value.

The next possible method to measure salinity is with the help of a refractometer. This instrument measures the difference between the wave length of light emitted from a source, passed through the measured water and captured in the refractometer. This means the refractometer knows wave lenght before pass through water and after that and by comparing these two values calculate the value of refraction. The substitution of this measured value into a table of known values of salinity means that the concentration of salts in water; salinity can be obtained (URI, 2001; Kameníček, 2009).

Salinity is not a stationary value as it changes over time depending on the amount of salt-salinity changing absolutely, or amount of water-salinity is changing relatively. We can calculate this proportion by using equation 1, see above (Kameníček, 2009).

For our research data measured by PROTE company in Darbandihkan dam's in the year 2008 is used (see fig. 8). This shows the level of contamination by various substancies.

Fig. 8, Contaminants in Water (PROTE, 2008; WHO, 2006).

Substance	Unit	Value	Limit
As	µg/l	1.70	10.00
Bromide	µg/l	1.50	10.00
Chlorides	mg/l	22.40	50.00
Cr	**µg/l**	**5.00**	**1.00**
Nitrates	mg/l	2.00	50.00
Fluorides	mg/l	0.20	1.60
Al	mg/l	0.02	0.20
Mg	mg/l	12.00	12.00
Cd	**µg/l**	**0.50**	**0.07**
Mn	mg/l	0.05	50.00
Cu	**µg/l**	**4.00**	**2.00**
Ni	µg/l	4.00	70.00
Pb	**µg/l**	**1.00**	**0.00**
Hg	**µg/l**	**0.20**	**0.00**
Se	µg/l	0.30	20.00
Na	mg/l	13.20	20.00
Ca	mg/l	65.50	75.00
Zn	**µg/l**	**34.00**	**5.00**
Fe	mg/l	0.10	2.00
Sulphate	mg/l	61.40	250.00

This table (fig. 8) shows the substances found in water in various forms, for example in the form of ion, oxide, hydroxide or various compounds with other substancies. In the second column are units and in the third the value of substancies which were measured in water (in the year 2008, see above). The last column shows the limit of substancies for potable water according to WHO, in 2006.

From the stated values it clearly follows that there are substancies which exceed their limit for potable water. There are chromium, cadmium, copper, lead, mercury and zinc. Also magnesium in a short time overstepped theWHO limit.

This data will be used for estimation of amount of these substancies in the future (see next).

For a better ilustration of the importance of these substancies and their inpact on human health table fig. 9 describes their effects on human organism of overstepping the allowed limit for potable water. The importance of using a harmless source of water for human health can be clearly seen.

Fig. 9, Table showing the Negative Effects of Substancies in Salinity on Human Organism (Bencko, 1995; Nečas, 2009; WHO 2006).

Substance	Limit	Unit	Negative effect on human organism
As	10.00	µg/l	Disrupts breathing and blood vessels. 200 mg taken orally causes death.
Bromide	10.00	µg/l	Damage to the digestive system, liver and kidneys. Carcinogenic.
Chlorides	50.00	mg/l	Renal failure.
Cr	1.00	µg/l	Damage mucosa of the gastrointestinal tract, skin, causing allergies. Carcinogenic and mutagenic effects.
Nitrates	50.00	mg/l	Childhood anaemia.
Fluorides	1.60	mg/l	Convulsions, salivation, sweating, calcification.
Al	0.20	mg/l	Damage to the central nervous system. Carcinogenic.
Mg	12.00	mg/l	Renal and endocrine failure. Carcinogenic.
Cd	0.07	µg/l	Damages respiratory system, kidneys, bones. Prostate cancer.
Mn	50.00	mg/l	Mental and neurological disorders. Depression and mania.
Cu	2.00	µg/l	Damage the digestive tract, liver, kidneys, inflammation of the skin.
Ni	70.00	µg/l	Irritating to the skin and cause dermatitis.
Pb	0.00	µg/l	Anaemia, damage to the nervous system, digestive tract, kidneys.
Hg	0.00	µg/l	Inhibition of enzymes. Damage to the nervous system, kidneys, lungs and skin.
Se	20.00	µg/l	Damages the immune system, hair loss.
Na	20.00	mg/l	Vomiting, diarrhea, diuresis, sweating, skin swellings.
Ca	75.00	mg/l	Inhibition of enzymes, respiratory system. Damage liver, kidneys, reproductive organs. Carcinogenic.
Zn	5.00	µg/l	Anaemia.
Fe	2.00	mg/l	Damage the digestive tract and vascular system.
Sulphate	250.00	mg/l	Damages skin, causing allergies.

4 Methodology

In this chapter the methods of research used will be described as well as the work process with data. Results are introduced in next chapture 5 Results.

4.1 Used Methods

The used methods are GIS, Landsat, PCA, Linear regresion and statistical programs. These are all described below.

4.1.1 GIS

Geographic information system (GIS) is a program which is useful for geographical data evaluation. It is used for many purposes, in this thesis only a small number are introduced

4.1.1.1 Principles and Application

GIS is a computer program, which analyses known and measurable data. GIS processes it and give interpretable output about the phenomena which we want to investigate. The universality in data and output quantity and variability from this programme makes it a powerful tool for many uses, not only in hydrology, but also in meteorology, soil science, urban management, agriculture, forestry, etc.

We can collect data and give it, like an assigment for GIS. Typically it is positional data, relating to the space of our interest. It could be the geographic position of objects, their quantity or quality. After that, we can see this data in a special, we can say a natural, context and what is the plus of this is that we can work with it in a new way of use. We can predict the behaviour of river flow in a deep valley during floods. With strongly defined condition (altitude, slope, amount of water, curvature, etc.) we can predict with high probability where the best place to build a dam is for example.

The disadvantage of this is that GIS calculates only with space (geographical, static dimension) not with temporal dimension changing over time. Concisely we can say, that this program can calculated and display the effects only in three dimensions (height, width, length, mathematically axis x, y, z and their combination respectively). In GIS we can not predict and display reality in time view, we can show only measured data in relationship to each other. GIS is not an ideal tool for time-spaced modeling (environmental or another), but it is relatively easy to use it in orientation in space (De By et al., 2001).

4.1.1.2 Work with GIS

We can describe three main working phases (De By et al., 2001).

- **Data preparation and entry**
  - First phase; data about study phenomenon collected, prepared and entered to the system. Collection of data is one of the most important phases. We need a sufficiently wide selection complex for quality analysis. More simply we can say a great amount of data gives better image about the studied phenomenon, in this case output isdetailed and we want to maximally similar model in comparison with reality.
- **Data analysis**
  - In this phase data needs are carefully assessed and in the next step analysed by the system and we can assign our requirements.
- **Data presentation**
  - In the final phase we acquired result and have to interpret them in proper way. It is up to us what we want to express or work with in next steps of our research.
  - We can choose type of data presentation. Mainly it is in the form of a map, 3D map, phenomenons can be summarized, compared to each other, measured in new consequences, in form of graph, etc.

When we want to shortly summarize GIS, we can introduce, that is computerized system, which gives measured data into desired consequences. Is very useful especialy in georeferencial schemes (De By et al., 2001).

4.1.1.3 Landsat

The Landsat program is a collection of data obtained by satelite observing missions organized by NASA and U.S. Geological Survey. There is data about satelite observations of Earth from space since 1972. This science is known as remote sensing and has evolved with landsat.

Landsat Satelites take digital photos of the Earth's surface at defined time intervals and send them to Earth. It gives great posibility to see the Earth surface overall in many measuring in long time interval. Then dynamic changes in natural and artificial processes for example.could be studied and compared Landsat je freeware program (NASA, 2013).

4.1.2 Principal Componentes Analysis (PCA)

Principal componentes analysis (PCA) can be considered as one of the basic methods of more dimensional statistics. The essence of this method is to decrease the original number of variables. This variables (in our case measured data) have to be correlated necessarily and their number is decreased by introducing new latent variables, which are not correlated.

After that latent variables are organized into a descending line. Such a variable which has the smallest part on clarification of total variance is neglected In another words we choose only those variables which mostly clarified the total variance (in the literature 90%-95% present as a cumulative ratio usually).

For every latent variable Lambda (λ) exists for which characterized variance of concrete component and as well as a possible compute λ like proper number of covariance matrix S(x).

As seen above, PCA is possible to be used only in the situation where the original variables are correlated, the stronger, the more it is possible to reduce their quantity and analogous, when variables are not correlated (or very weakly) then the number of new latent variables is similar to the number of original variables.

PCA is a linear analysis method, because new latent variable is linear combination of original variables. Matematicaly we can derive:

$$|S(x) - \lambda I| l = 0 \qquad [2]$$

Where ***S(x)*** is the covariance matrix, ***I*** is theidentity matrix, ***l*** is the vector of parametres and ***λ*** proper number of matrix.

From the description of PCA it follows that this method is used for data adaptation and the basic division of data into linear asymptomatic clusters (Meloun and Militký, 2006).

4.1.3 Linear Regression

Regression is a statistical method which deals with the creation of functional relationships among variables. The principle of this method is to explain one variable by help of another variable. In this thesis parabolic regression will be used. The objective is to create an equation in the form:

[3] $$y=b_0+b_1x+b_2x^2$$

In the case of linear regression functions and linear regress functions from the point of view of parametres, we use the matrix of regresor's values:

[4] $$X=[1\ldots1;x_1\ldots x;_n x_1^2\ldots x_n^2]$$

This matrix is used for the expression of a concrete regression function. As a next step this matrix is used for the calculation of *b vector* by using it in the next equation.

[5] $$b=(XX^T)^{-1}Xy^T$$

Where ***b*** is the estimation of parametres, ***X*** is the matrix of regressors and ***y*** is vector of results (Meloun and Militký, 2006).

4.1.4 Statistical Programms

In this thesis a few programs for data analysis and interpretation were used. Two freeware programs for statistical data processing were used. These were Scilab 5.4.0 and Project R. Scilab is similar to Project R opensource.

Scilab is based on the Java programming language. It is a complete program not only for statistical calculations but also for mathematical modeling. For example Dassault company use this product. In this thesis it will be used for the PCA and Linear regression.

Project R is based on the Python programming language. It will be used for correlation analysis.

For the data interpretation of tabular or graphic forms **Microsoft Excel** was used too.

4.2 Working Process

Like data for GIS program, maps from Landsat were used. The advantege of this system are the coordinates, which means that the maps are georeferenced. In setings Asia was select as the coordination system.

For every year another layer-map was used to obtain a dynamic model of the Aral Sea surface changing.

For every layer it was important to mark the boundary of the sea surface and the land. With this check points can GIS work and than could be data combined.

In this thesis maps of surface area for years 1973, 1986, 1999, 2001, 2005, 2010, 2013 are shown This maps are shown individualy (fig. 8) sumationately for better shown of dynamic changes (fig. 9) and like intersection for show of presence permanent water area (fig. 10).

This data were also used for the next calculation in this thesis. In this thesis are used measured data (Placák, 2013) combined with data from Ing. Miroslav Šobr Disertation thesis (Šobr, 2009) (see fig. 10).

Fig. 10, Development of Water Surface Area (Placák, 2013; Šobr, 2009).

Year	1960	1965	1970	1973	1975	1980	1985	1986	1989
Surface area [x 1000 km2]	67.90	63.90	60.40	57.84	57.20	52.40	44.40	44.40	37.00
Year	1992	1998	1999	2001	2003	2005	2010	2013	
Surface area [x 1000 km2]	33.50	22.50	29.47	29.53	18.20	19.80	19.97	20.79	

This GIS measured data, especialy the surface of the water area was used for the next calculations. This was compared with other data and other necessary data from past year was added by (Šobr, 2009). These values are shown in table (fig. 11). There are values of the **altitude** of surface water level *[m]*, **surface area** *[km²]*, **water volume** *[km³]*, **salinity** *[g/l]* and **river inflow** of water into the sea *[km³]*.

It is possible to create a comparative graph (fig. 11) but these values have negligible value.

Year	1960	1965	1970	1975	1980	1985	1989	1992	1998	2003	Average	Variability
Altitude [m]	53.30	52.50	51.60	49.40	46.20	42.00	39.00	36.50	33.50	31.00	43.50	7.83
Surface area [x 1000 km2]	67.90	63.90	60.40	57.20	52.40	44.40	37.00	33.50	22.50	18.20	45.74	16.55
Water volume [Km3]	1090.00	1030.00	970.00	840.00	670.00	470.00	340.00	270.00	210.00	113.00	600.30	347.43
Salinity [g/l]	10.00	10.50	11.10	13.70	16.50	23.50	28.00	34.40	48.10	78.00	27.38	20.53
River inflow [Km3]	40.00	31.00	33.00	11.00	0.00	0.00	5.00	0.00	0.00	0.00	12.00	15.35

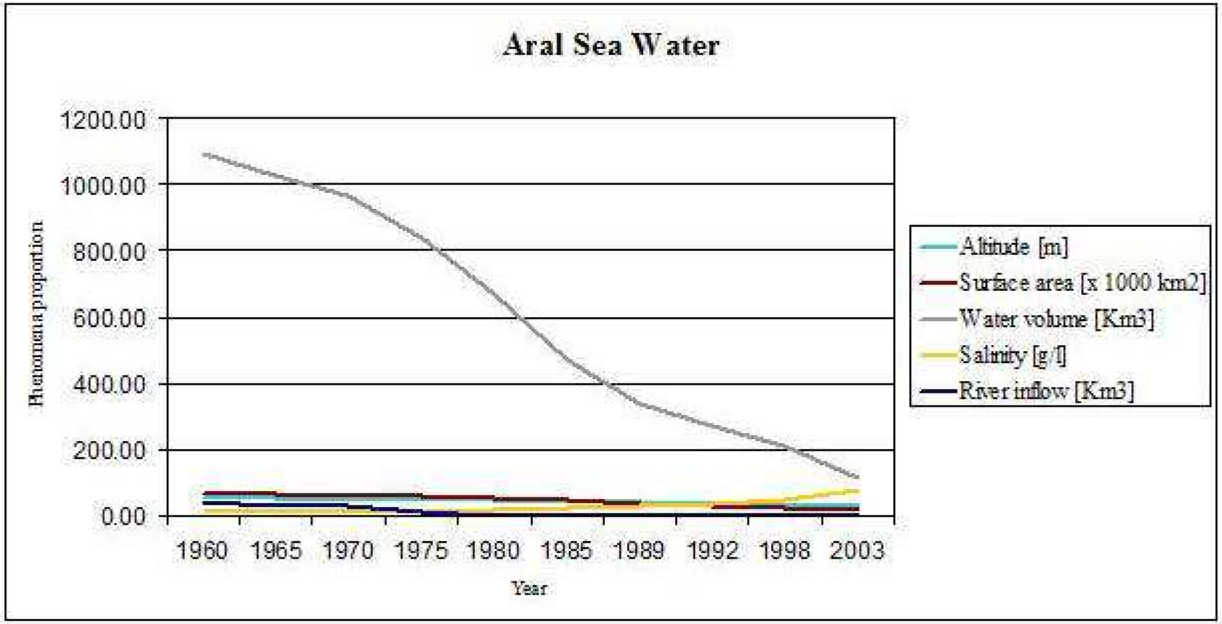


Fig. 11, Uncentred Matrix (Placák, 2013).

For a better understanding of this phenomena and for better graphical ilustration there is also a matrix of these values centrated. For matrix centration we need the average value of the actual phenomena and variability (see table fig. 11). Values in centrated matrix will be be obtained by using:

[6] $$A=\Sigma_i\Sigma_j\,(a_{ij}-\bar{a}_i)/s_i$$

Where ***A*** is centrated matrix, ***j*** and ***i*** are position of number a in the matrix, ***s*** is variability.

A graph of the centrated matrix shows more an ilustrative comparision between the main phenomena, especialy the decreasing amount of water in different ways toward rising salinity (fig. 12).

Year	1960	1965	1970	1975	1980	1985	1989	1992	1998	2003
Altitude [m]	1.2522	1.14998	1.03498	0.75387	0.34499	-0.1917	-0.575	-0.8944	-1.2778	-1.5972
Water surface area [x1000 km2]	1.33922	1.09749	0.88597	0.69258	0.40249	-0.081	-0.5282	-0.7397	-1.4045	-1.6644
Water volume [km3]	1.4095	1.2368	1.0641	0.68993	0.20062	-0.375	-0.7492	-0.9507	-1.1234	-1.4026
Salinity [g/l]	-0.8466	-0.8223	-0.7931	-0.6664	-0.53	-0.189	0.0302	0.34197	1.00935	2.4659
River inflow [km3]	1.82419	1.23784	1.36814	-0.0651	-0.7818	-0.7818	-0.456	-0.7818	-0.7818	-0.7818

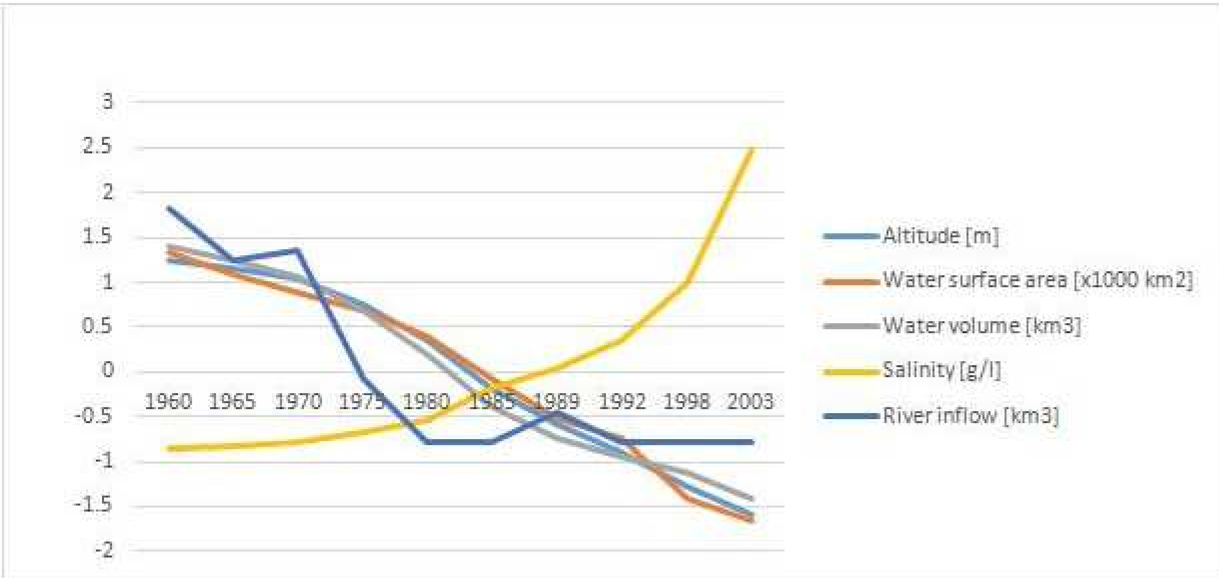


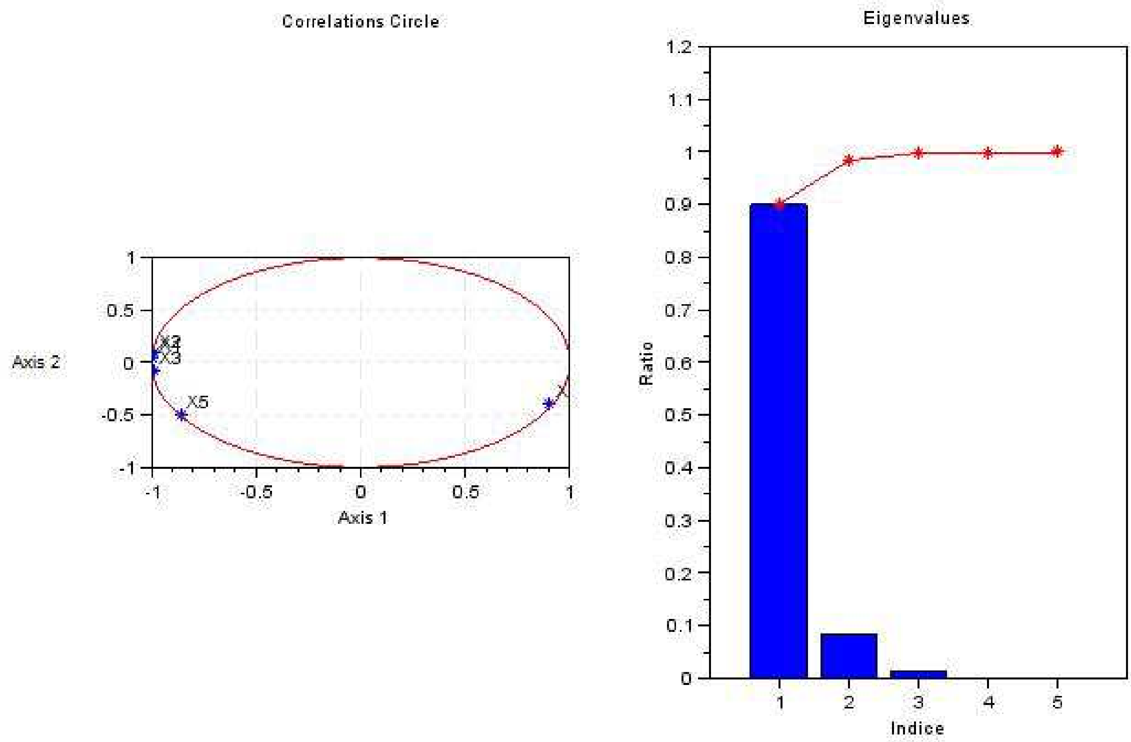
Fig. 12, Centred Matrix (Placák, 2013).

Fig. 13, Correlation Matrix (Placák, 2013).

	Year	Altitude	Surface area	Volume	Salinity	River inflow
Year	1.0000000	-0.9848574	-0.9859792	-0.9872691	0.8799447	-0.8726229
Altitude	-0.9848574	1.0000000	0.9950726	0.9906545	-0.9027070	0.8163859
Surface area	-0.9859792	0.9950726	1.0000000	0.9787893	-0.9189183	0.7935570
Volume	-0.9872691	0.9906545	0.9787893	1.0000000	-0.8489773	0.8709156
Salinity	0.8799447	-0.9027070	-0.9189183	-0.8489773	1.0000000	-0.6039875
River inflow	-0.8726229	0.8163859	0.7935570	0.8709156	-0.6039875	1.0000000

In the correlation matrix (fig. 13) we can see the correlation coefficients of the main phenomena compared to each other. From the value of the correlation coefficients it clearly follows that these trends are linear (coefficients are mainly biger than 0.9, at least 0.8). Data from correlation matrix are used for PCA.

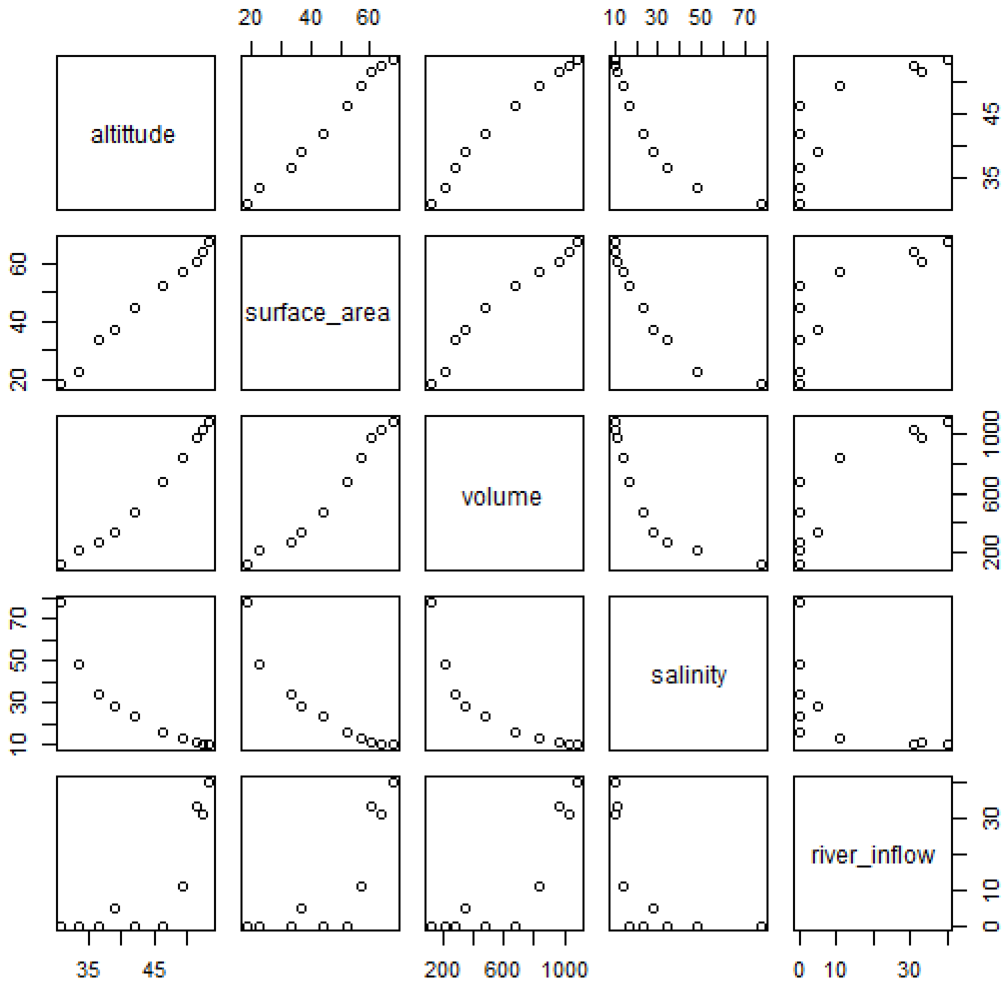
Fig. 14, Result of PCA Method (Placák, 2013).



The PCA method shows that in the above group of related data one significant linear trend exists (see fig. 14). Size of lambda (λ) explains approximately 90% of the data's variability.

The Analysis of PCA and correlations of individual original variables shows a strong linear trend not only of all data but also of its individual variables (see fig. 15).

Fig. 15, Linear Correlation of Individual Variables To Each Other (Placák, 2013).



For water salinity progress estimation a time series was used showing the changes from year 1960 until the newest found monitor dating from 2003. A regression parabola was used for the reason that Aral Sea region is an area without a significant outflow, which signifies that salt accumulates there. Also the determination index is higher for parabolic function (0.97) than for a linear function (0.77). This assumption is also confirmed by the shape of salinity development in the centred matrix graph (see fig. 12).

By regression analysis (see capture 4.1.3. Linear Regresion) it was discovered that:

[7] $$[y]=211713.4-215.02637[x]+0.0546001[x]^2$$

Where ***y*** is salinity [$^g/_l$] and ***x*** is year and the equation now corresponds to the form of equation 3.

This equation was used for the following estimation of Aral Sea water salinity future changes in table and graph (see fig 23, 24). Also it is necessary to take into consideration dissolvability of salts in water. Above this value each salt will not dissolve in water, but stay as a sediment on the bottom of the Sea. The reference value used in this thesis is the dissolvability limit for soduim chloride, which is the main part of Aral Sea salinity. The value of solubility in water is 358. 6 $^g/_l$ (Vohlídal et al., 1999).

The year's calculation when salts dissolved in the water will be on the top of dissolvability patterned on equation 7. As the value of salinity (y) we will substitute the value of solubility of salt in water (see above). We obtain:

[8] $$358.6=211713.4-215.02637[x]+0.0546001[x]^2$$

The result of this equation is x = 2048, it signifies that in the year 2048 the dissolved mass of salts in water will reach the maximum, after this point any new salts in the sea will be sediment.

In this case we can calculate the salinity forecast until year 2048. The amount of dissolved substances will be estimate from these values for total salinity.

We started in the year 2008 when the values of substancies in water were measured. From equation 7 (see above) where year (x) is 2008, we obtain salinity (y) for this year, the year of measurement, it was 91.55 $^g/_l$ In the next step we calculate the representation of substancies in total salinity in ppm. Outcomes are in table, fig. 16:

Fig. 16, Substancies in ppm of Total Salinity in Year 2008 (Placák, 2013).

Substance	ppm in 91.55 $^{g}/_{l}$
As	$1.857 \cdot 10^{-2}$
Bromide	$1.638 \cdot 10^{-2}$
Chlorides	$2.447 \cdot 10^{2}$
Cr	$5.461 \cdot 10^{-2}$
Nitrates	21.85
Fluorides	2.185
Al	0.2185
Mg	$1.311 \cdot 10^{2}$
Cd	$5.461 \cdot 10^{-3}$
Mn	$5.243 \cdot 10^{-1}$
Cu	$4.369 \cdot 10^{-2}$
Ni	$4.369 \cdot 10^{-2}$
Pb	$1.092 \cdot 10^{-2}$
Hg	$2.185 \cdot 10^{-3}$
Se	$3.277 \cdot 10^{-3}$
Na	$1.442 \cdot 10^{2}$
Ca	$7.155 \cdot 10^{2}$
Zn	0.3714
Fe	1.092
Sulphate	$6.707 \cdot 10^{2}$

If we presume the relative representation of the included substancies in total salinity is constant during the next years, we can calculate the amount of substancies in the following years in ppm and total salinity from equation 7.

In this thesis the values for years 2008 and 2048 are calculated to show the change over time. Salinity in the year by equation 7 (corresponds with equation 8) will be 358. 6 $^{g}/_{l}$. See fig. 17:

Fig. 17, Amount of Substancies in Water in the Year 2008 and 2048 (Placák, 2013; PROTE, 2008; WHO, 2006).

Substance	Unit	Value 2008	Value 2048	Limit
As	µg/l	1.70	6.70	10.00
Bromide	µg/l	1.50	5.90	10.00
Chlorides	**mg/l**	**22.40**	**87.70**	**50.00**
Cr	µg/l	5.00	19.60	1.00
Nitrates	mg/l	2.00	7.80	50.00
Fluorides	mg/l	0.20	0.80	1.60
Al	mg/l	0.02	0.10	0.20
Mg	**mg/l**	**12.00**	**47.00**	**12.00**
Cd	µg/l	0.50	2.00	0.07
Mn	mg/l	0.05	0.20	50.00
Cu	µg/l	4.00	15.70	2.00
Ni	µg/l	4.00	15.70	70.00
Pb	µg/l	1.00	3.90	0.00
Hg	µg/l	0.20	0.80	0.00
Se	µg/l	0.30	1.20	20.00
Na	**mg/l**	**13.20**	**51.70**	**20.00**
Ca	**mg/l**	**65.50**	**256.60**	**75.00**
Zn	µg/l	34.00	133.20	5.00
Fe	mg/l	0.10	0.40	2.00
Sulphate	mg/l	61.40	240.50	250.00

This table (fig. 17) clearly shows substancies which exceed their limits for potable water. There are chlorides, magnesium, sodium, calcium. Other substancies (Cr, Cd, Cu, Pb, Hg and Zn) which exceeded their limit at the time of measuring are not included in the following calculations.

The results we want to show are when did substances which exceeded their limits for potable water during the period 2008 - 2048 actually reach their limit. For salinity (y) in equation 7 we substitute the value when is the limit for potable water for each substance reached. The result of equation (x) is the year when the limit is reached. See chapture 5 Results, fig. 25.

5 Results

Fig. 18, 19, 20 clearly shows the constant decrease of the surface area of the Aral Sea with GIS maps. These changes are also shown in a graph (Fig. 21).

Fig. 18 shows the changes of water surface area since from 1973 till 2013. This phenomenon is shown individually on maps with scale. Values are in table fig. 22.

Fig. 22, Water Surface Area by GIS (Placák, 2013).

Year	1973	1986	1999	2001	2005	2010	2013
Surface area [x1000 km^2]	57.84	44.40	29.47	29.53	19.80	19.97	20.79

Fig. 19 shows these maps in comparison to each other for the better ilustration of the decrease in Sea surface area.

Fig. 20 represent permanent water area, it is the intersection of water areas measured from 1973 to 2013. It is the surface of land, which has never been without water until today. We can estimate the massive salt deposits that will be there in the future. The permanent water area measure approximately 17, 900 km^2.

Fig. 21 graphicaly shows the decrease of the surface area of the Aral Sea during the years 1960 to 2013. Data is combined with data from the dissertation thesis of Miroslav Šobr from year 2009. This graph coresponds with fig. 10, on page 31.

Fig. 18, Water Surface Changes in Time, Shown Individually (Placák, 2013).

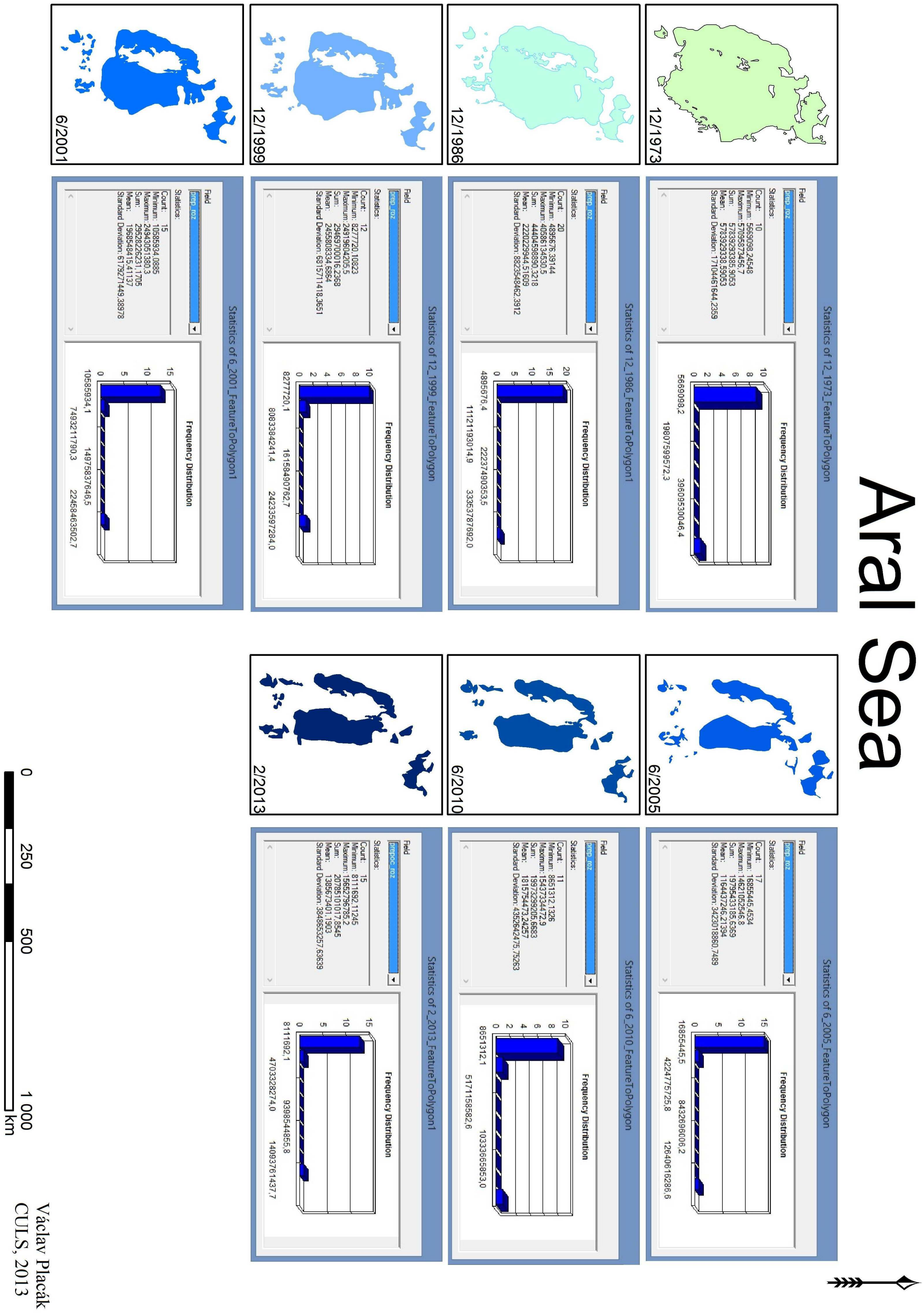


Fig. 19, Water Surface Changes over Time. Shown Individually and in Superimposed to Each Other (Placák, 2013).

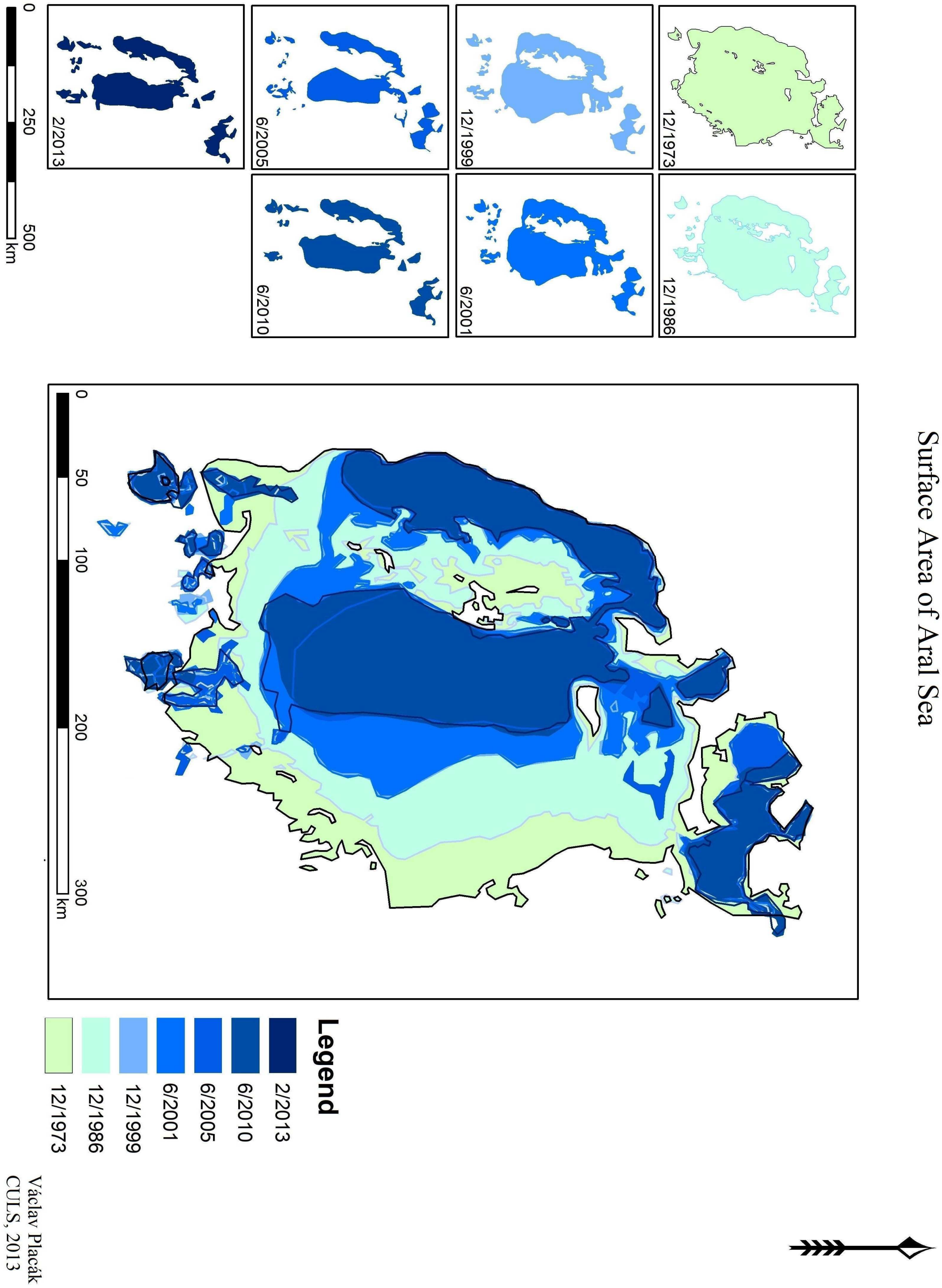


Fig. 20, Permanent Water Area of Aral Sea (Placák, 2013).

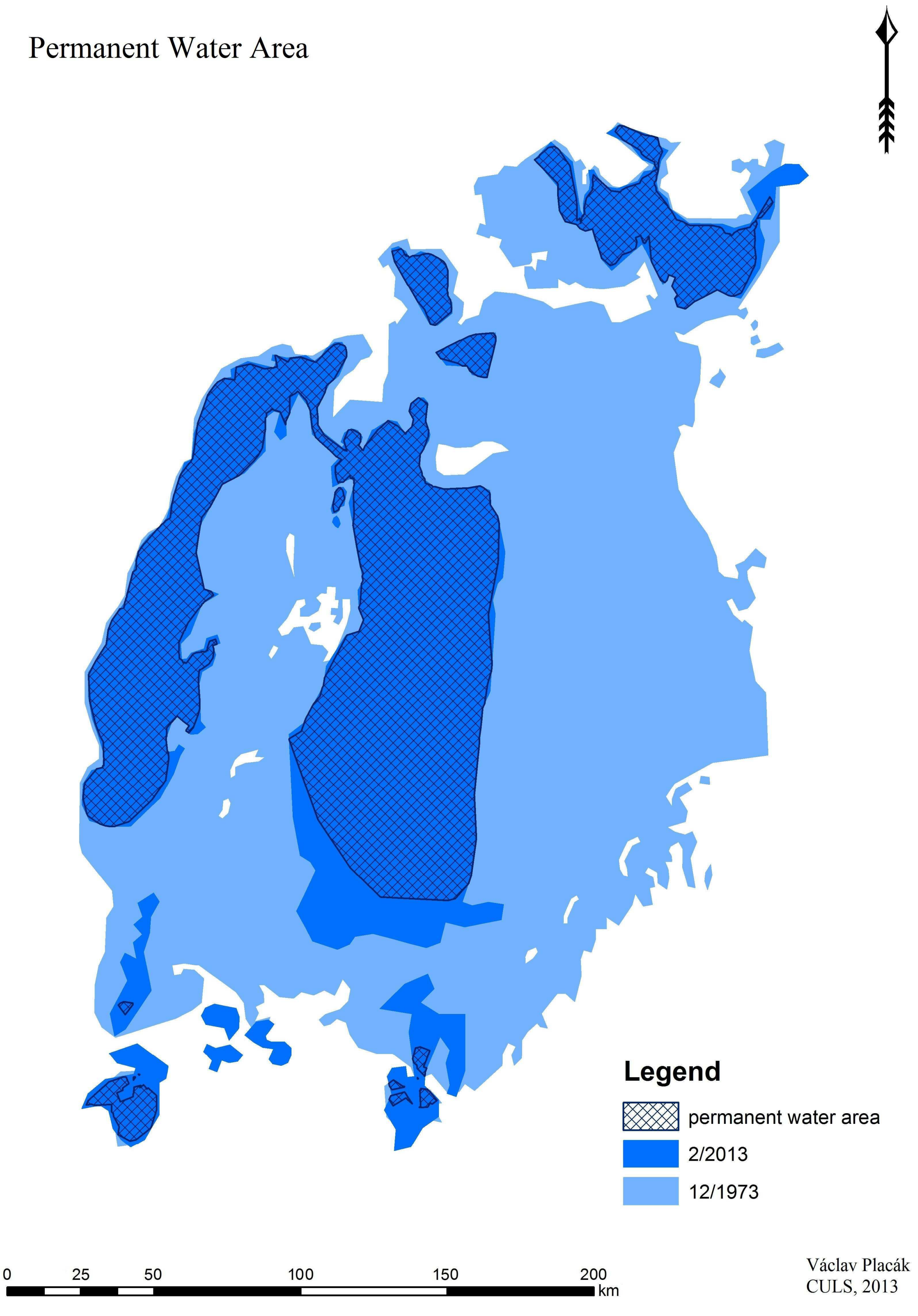
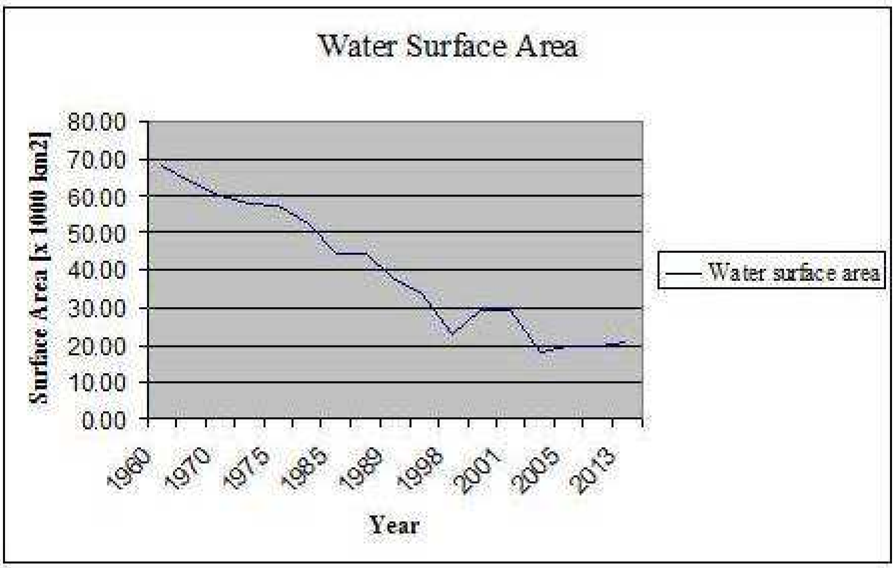


Fig. 21, Changes in the Water Surface Area (Placák, 2013; Šobr, 2009).



The phenomenon of the decrease in the surface area of the Aral Sea is strongly related with the decrease of water volume in the Aral Sea, which is mathematicaly proved by correlation analysis and PCA method in this thesis. These trends are strongly correlated, which makes them linearly dependent.

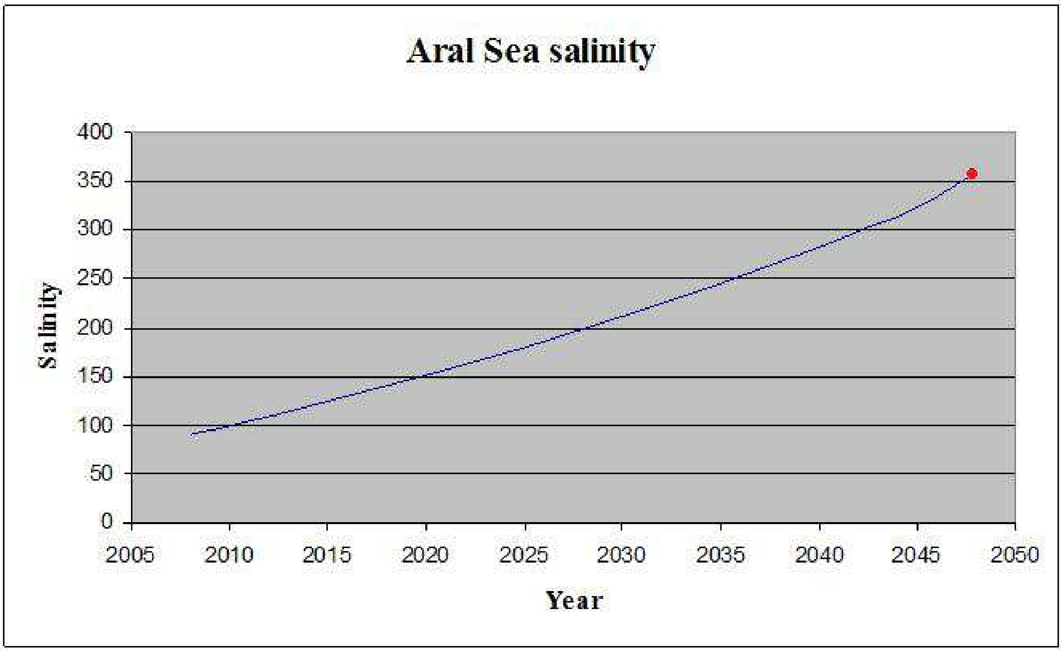
PCA analysis proves the very strong linear trend-approximately 90% - in this linear dependance (fig. 14). This signifies that one variable can be estimated by its dependance on another, in our case water surface area in correlation with salinity (fig. 15).

In this thesis the schema of Aral Sea salinity from 2008 till 2048 made by Linear regression method is shown. See fig 23, 24.

Fig. 23, Table of Salinity Changes from 2008 till 2048 (Placák, 2013).

Year	Salinity [$^g/_l$]
2008	91.55
2010	100.26
2015	123.96
2020	150.38
2025	179.54
2030	211.42
2035	246.04
2040	283.38
2045	323.46
2048	358.61

Fig. 24, Graph of Salinity Changes from 2008 till 2048 (Placák, 2013).



Graph of salinity shows a parabolic increase. The curve starts from year 2008 where total salinity was 91. 55 $^g/_l$ and ends in the year 2048 when salinity is estimated as approximately 358. 61 $^g/_l$, when salts reach their limit of solubility. The years when substancies exceed their limit are shown in table (fig. 25). Magnesium and calcium exceeded their limits before this thesis was writen, but after the data used was measured. Chromium, cadmium, copper, lead, mercury and zinc exceeded their limit before year 2008 and other substances did not reach their limit for potable water by 2048.

Chlorides, Magnesium, sodium and calcium reached and then exceeded their limit during this time and these substancies could be a problem for human health (see fig. 9, chapture 3 Salinity).

Fig. 25, Table of Years when Amount of Substances Exceeded their Limit for Potable Water (Placák, 2013).

Substance	Unit	Value 2008	Year limit is exceeded	Limit
As	µg/l	1.70	+	10.00
Bromide	µg/l	1.50	+	10.00
Chlorides	mg/l	22.40	2029	50.00
Cr	µg/l	5.00	-	1.00
Nitrates	mg/l	2.00	+	50.00
Fluorides	mg/l	0.20	+	1.60
Al	mg/l	0.02	+	0.20
Mg	mg/l	12.00	2008-9*	12.00
Cd	µg/l	0.50	-	0.07
Mn	mg/l	0.05	+	50.00
Cu	µg/l	4.00	-	2.00
Ni	µg/l	4.00	+	70.00
Pb	µg/l	1.00	-	0.00
Hg	µg/l	0.20	-	0.00
Se	µg/l	0.30	+	20.00
Na	mg/l	13.20	2018	20.00
Ca	mg/l	65.50	2011*	75.00
Zn	µg/l	34.00	-	5.00
Fe	mg/l	0.10	+	2.00
Sulphate	mg/l	61.40	+	250.00

6 Discussion

Although all parts of the thesis are associated with each other this chapter is divided into several parts for greater clarity.

6.1 Results from GIS

Results from GIS have value for this thesis. They show us the decrease of the water surface area and areas with greater future salinity with masive deposits of salt could be estimated. The permanent surface area could show this.

Unfortunately in our case water volume can not be calculated by GIS. We have not countour lines of the Aral Sea bottom for GIS programme so we can not calculate other values like water volume or altitude of surface. This signifies that other data about water suface and the actual water volume are used. But our GIS results clearly shows the change of surface area over time since year 1973; there was not any older satelite photo available.

Graph fig. 21 indicates the rise of Sea surface area during years 2000-2003. It could be a real phenomenon caused by a temporary improvment of water inflow from rivers or rainfall or propably it could be a mistake in the conditions defined in measurement.

6.2 Corelation between Main Phenomena of Aral Sea Water

A strong correlation between variables, namely suface area, altitude, water volume, river inflow and salinity was proved. This was important for the next calculations and for the selection of method to use for salinity estimation. Even though there were not much data available for calculation, the correlation was very strong and values were linearly dependent.

Many factors effect River inflow. It is decreased by loss from irrigation, evaporation and seepage. The decrease of volume from the Pamir Glaciers is also included.

6.3 Schema of Possible Future Situation of Aral Sea Water Salinity

In this thesis a schema for future Aral Sea salinity estimation is shown. It is based on historic data, which signifies the deduction of future events from the past. This method supposes the same progress of events in the future as took place in the past and excludes great changes in conditions in the Aral Sea region, such as change of infrastructure, agriculture, industry etc. which could cause the situation to get worse or better. It is not the best method, because unexpected scenarios or improvements are ignored. Interventions are not allowed.

Environmental modeling is better (Haag et al., 2011) as it predicts future conditions from a great amount of data and can synthetize them into a more complex function even if the conditions are changed. We can change them in the model also. This system can estimate the progress of future more precisely but is very exacting on data and the methodology used. Also it is expensive and demanding on creation.

Only a few authors apply future salinity forecasting in their work. Only one known scientist is applying environmental modeling in Pamir Mountains (Haag et al., 2011), see above.

In this case we can say that our method is cheap and quick and could be useful for proportionated estimation.

The results in table and graph (fig. 23, 24), of the future total salinity estimation until year 2048 include data for the year when the water becomes a saturated solution. After that salts start accumulating at the bottom.

Results in table (fig. 25) show the substances which exceeded their limit for potability and when this ocured and which need special methods of water purification. The dangers of these pollutants are shown in chapter 3 Salinity in table 9.

7 Conclusion and Recommendation

From the data found and that it clearly follows that situation in the Aral Sea region will get worse in the future. Salinity will rise almost exponentially, because salt accumulates there and there is not an easy way to dispose of it. We can clean water, but only for local purposes. Even this brings many problems; economic or the dumping of polutants from the water.

There are many environmental and ecological problems which are still increasing and geting worse. This *circulus vitosus* without implementing a plan of action could have only one possible result; environmental disaster.

This tragic situation is not only the consequence of regional factors (irrigation, fertilization, monocultures, etc.) but global conditions also. The melting of the Pamir Glaciers due to global warming for example. Also the economic situation forces the growth of cotton in this region to continue.

In this region international scientific intervention is need definitely. This is the last hope for environmental, ecological and even economic conditions to improve or at stabilize. This region needs an efective and economicaly acceptable long-term solution.

For the future estimation of conditions in this region the best way will be environmental modeling. But the adventages of the salinity estimation method, which is demonstrate, are the speed of delivery and low price in the short time. As almost all the biota in the Aral Sea region is extinct, the estimation of future salinity can be used to improve living standards in this region.

To provide a solution to this situation we can recommend as a first step to cease growing monoculture crops (cotton species today) and start growing other plants which are more adaptable to the situation or require less water. The next step could be improving the quality of irrigation canals as there is great loss of water from the existing ones. Also using fewer chemicals for fertilization or other purposes.

More expensive solutions like the building of dams to help replenish the Aral Sea, redirecting water from rivers like Ob, Volga or Irtysh Rivers for example could be employed. Pumping water from the Caspian Sea via pipeline is also a possible long term solution.

8 Annexes

Fig. 1, Map of Aral Sea and Position in Middle East (UniMaps.com. 2005).

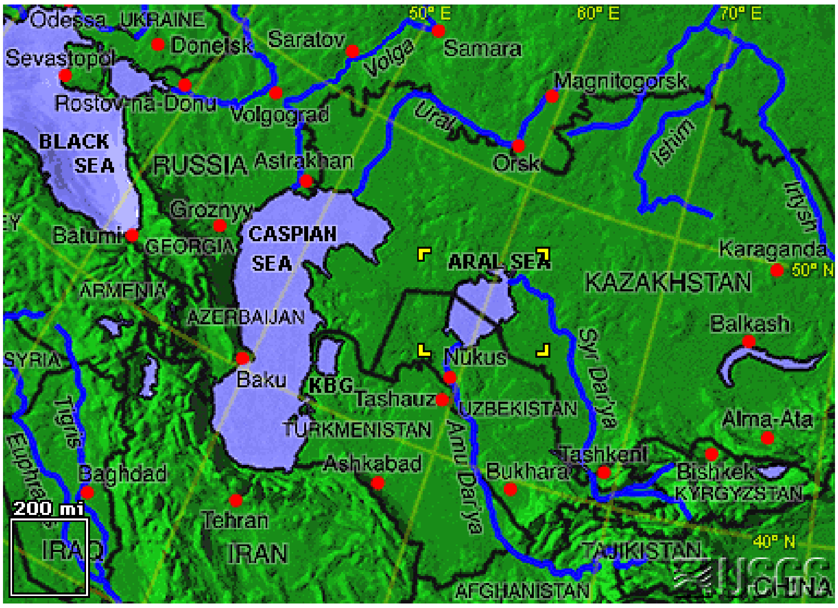


Fig. 2, Map of Amu-Darya and Syr-Darya (Water Rhapsody, 2011).

(1: 10 000 000).

Fig. 3, Map of Amu-Darya and Part of Pamir Mountains where the River originates (Demis.nl). (About 1900 km across).

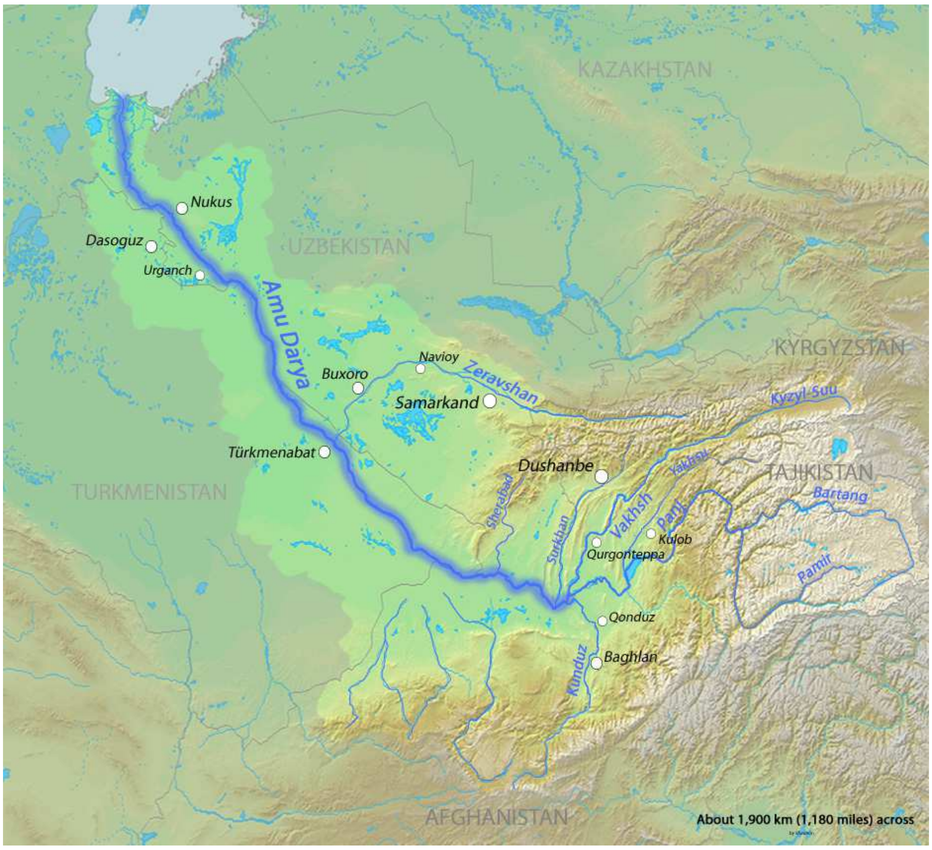


Fig. 4, Map of Syr-Darya and Part of Pamir Mountains Where River Originates (Demis.nl). (About 3000 km across).

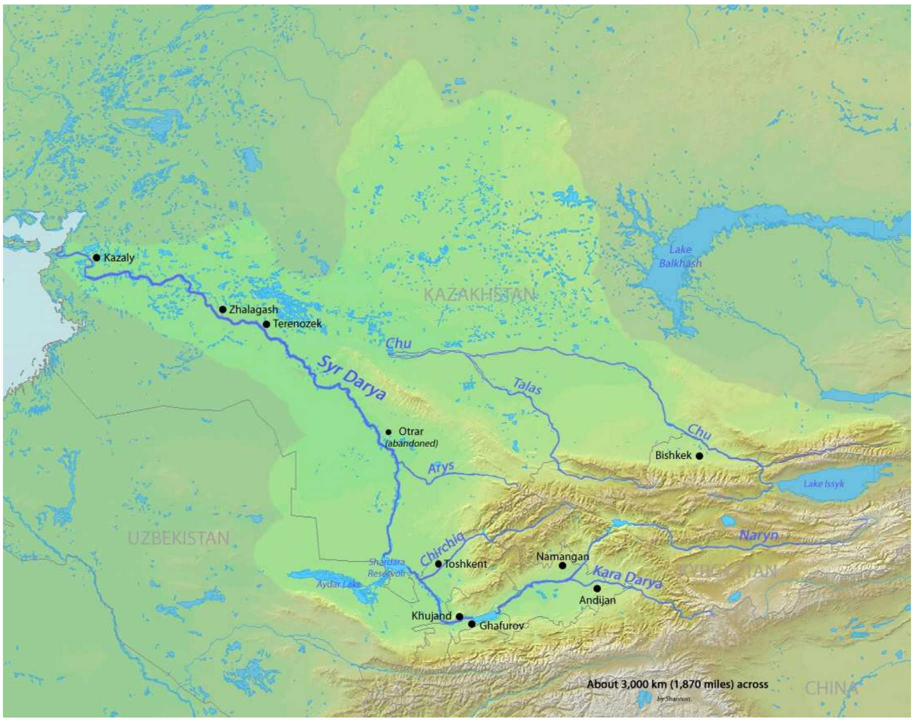


Fig. 5, Changes of Aral Sea Coastline Position (Mappery.com, 2010).

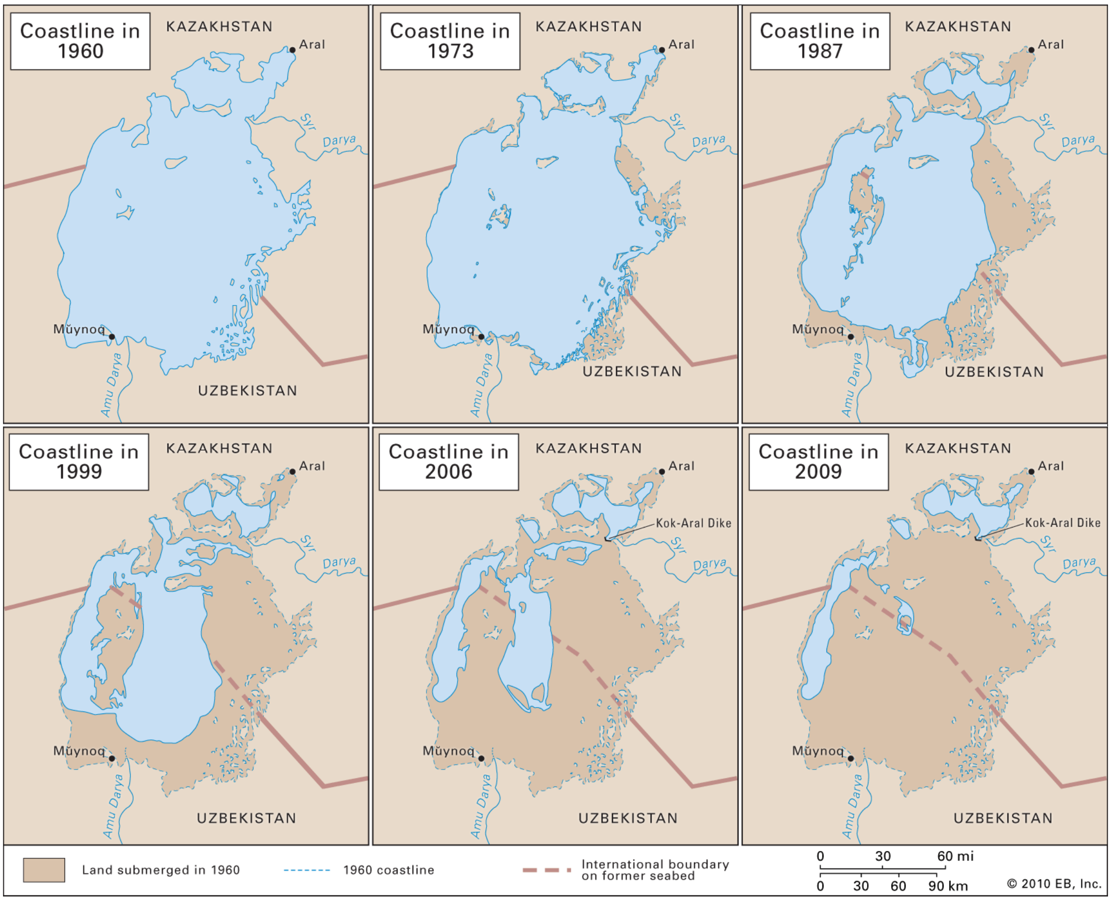
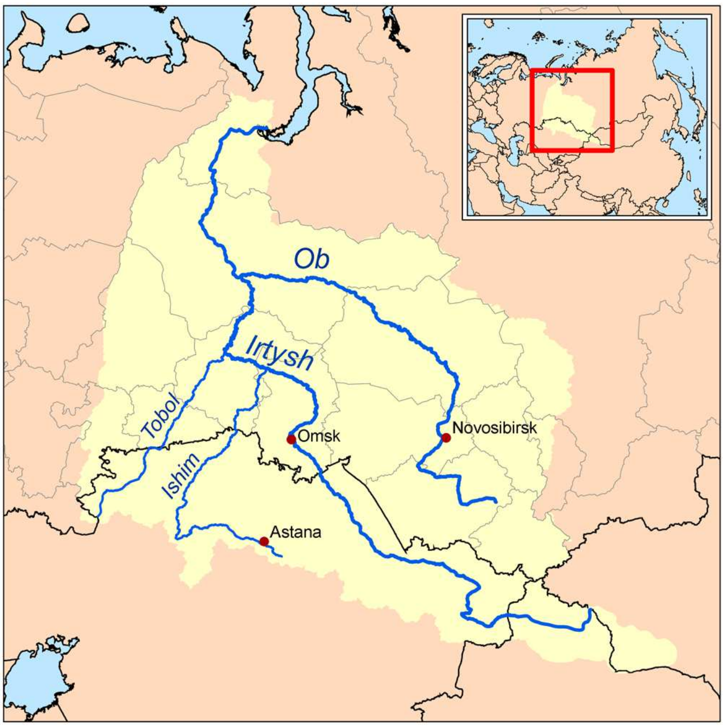


Fig. 6, Satelite Photo Documented Decrease of Aral Sea Surface Area (NASA, 2009).

Fig. 7, Map of Ob River Watershed at the Confluence with Irtysh River (Musser, 2011). (1:10 000 000).



9 References

Akhtar A, Ahmad N, Booij M. J. 2008. The impact of climate change on the water resources of Hindukush – Karakorum – Himalaya region under different glacier coverage scenarios, J. Hydrol., pp 148–163.

Aladin N. V, Plotnikov I. S, Micklin P, Ballatore T. 2009. Aral Sea: Water level, salinity and long-term changes in biological communities of an endangered ecosystem-past, present and future. In: Natural Resources and Environmental Issues, Volume 15 Saline Lakes Around the World: Unique Systems with Unique Values [online]. Utah. Available at http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1263&context=nrei (accesed on 23 March 2013).

Barnett T, Adam J, Lettenmaier D. 2005. Potential impacts of a warming climate on water availability in snow dominated regions, Nature, pp. 303–309.

Bekchanov M, Lamers J. P, Martius C. 2010. Pros and Cons of Adopting Water-Wise Approaches in the Lower Reaches of the Amu Darya: A Socio-Economic View. Water, 20 (2): 200– 216.

Bencko V, Cikrt M, Lener J. 1995. Toxické kovy v životním a pracovním prostředí člověka. Praha. Grada Publishing, 64 pp.

Benduh F, Renard P. 2004. A dynamic model of the Aral Sea water and salt balance. In: Science Direct: Journal of Marine System [online]. Neuchatel: Switzerland. Available at http://geolep.epfl.ch/webdav/site/geolep/shared/coursaral/fichiers/Articles/mer%20d'aral%20 Renard.pdf (accesed 23 February 2013).

Bissell T. 2008. Eternal Winter: Lessons of the Aral Sea Disaster. Harper's. pp 41–56

Conrad C, Dech S. W, Hafeez M, Lamers J. P. A, Martius C, Strunz G. 2007. Mapping and assessing water use in a Central Asian irrigation system by utilizing MODIS remote sensing products, Irrig. Drainage Syst., 21 (6): 197–218.

De By A. R, Knippers A. R, Sun Y, Ellis C. M, Kraak M. J, Weir C. J. M, Georgiadou Y, Radwan M. M, van Westen C. J, Kainz W, Sides E. J. 2001. Principles of Geographic Informational System: An introductory textbook. In: de By Rolf A. ITC Educational

Textbooks Series 1 [online] Entschede: Netherlands. Available at http://www.gdmc.nl/oosterom/PoGISHyperlinked.pdf (accesed on 23 March 2013).

Demis.nl. Not Dated. Demis World Map Server [online]. Delft: Netherlands. Available at http://www2.demis.nl/mapserver/mapper.asp (accesed at 22 March 2013).

Froebrich J, Kayumov O. 2004. Water management aspects of Amu Darya: Dying and Dead Seas – Climatic Versus Anthropic Causes. Dordrecht. Kluwer Academic Publishers, pp 49–76.

Glantz M. H. 2005. Water, climate, and development issues in the Amu Darya Basin: Mitigation Adaptation Strategies Global Change. Nature, 10 (7): 23–50.

Hagg W, Braun L. N, Uvarov V, Makarevich K. G.2004. Comparison of three methods for mass balance determination in the Tuyuksu glacier region, Tien Shan. J. Glaciol, pp 505–510.

Hagg W, Braun L. N, Weber M, Becht M. 2006. Runoff modeling in glacierized Central Asian catchments for present-day and future climate, Nord. Hydrol, pp 93–105.

Hagg W, Braun L. N, Kuhn M, Nesgaard T. I. 2007. Modeling of hydrological response to climate change in glacierized Central Asian catchments. J. Hydrol, pp 40–53.

Hagg W, Shahgedanova M, Mayer C, Lambrecht A, Poponin V. 2010. Sensitivity study for water availability in the Northern Caucasus based on climate projections. Global Planet Change, 73 (8): 161–171.

Haag W, Hoelze M, Wagner S, Klose Z. 2011. Estimation of future glaciation and runoff in the Tanimas basin, Eastern Pamirs. In: Hydrology and Earth System Sciences Discussions [online]. Copernicus Publications. Available at https://www.email.cz/download/i/7qGyaUxKCTWp4GtmgOPeD1DTSotV8bxb31uJ5GTk-BcB_sTDjzvKMerZLOP2ZThvM_FE-z8/hessd-8-1507-2011.pdf (accesed on 3 April 2013).

Huss M, Jouvet G, Farinotti D, Bauder A. 2010. Future high-mountain hydrology: new parameterization of glacier retreat. Hydrol, Earth System Science, 14 (3): 815–829.

ICWC. 2010. Basin Water Organization "Amudarya" [online] Tajikistan. Available at http://www.icwc-aral.uz/bwoamu.htm (accesed on 13 March 2013).

Johannesson T, Raymond C, Waddington E. 1989. Time-scale for adjustment of glaciers to changes in mass balance. J. Glaciol, 12 (1): 355–369.

Kameníček J. 2009. Anorganická chemie. Olomouc. Univerzita Palackého v Olomouci, 316 str.

Krepl V. 2008. Project 81/04-06/MZe/B Report. Improvement of the Quality of Drinking and Irrigation Water in the Aral Sea Region by Cleaning Equipment and Sorbents Produced in the Czech Republic. Ministry of Agriculture of CR, Prague. (PROTE company).

Lambrecht A, Mayer C, Surazakov A, Aizen V. 2010. Changes of Fedchenko Glacier, Pamir, during the last 81 years. Vienna, Austria. EGU General Assembly, pp 352.

Létolle R, Mainguet M. 1996. Der Aralsee-Eine Ökologische Katastrophe. Springer Verlag, Berlin, 517 pp.

Mappery.com. 2010. Aral Sea History Coastline Map [online]. Available at http://mappery.com/map-of/Aral-Sea-historic-coastline-Map (accesed on 3 April 20013).

Martius C, Froebrich J, Nuppenau E. A. 2009. Water Resource Management for Improving Environmental Security and Rural Livelihoods in the Irrigated Amu Darya Lowlands. HexagonSeries on Human and Environmental Security and Peace, 4, pp 749–761.

Meloun M, Militký J. 2006. Kompendium statistického zpracování dat. Prague. Academia, 970 pp. ISBN 80-200-1396-2.

Micklin P. 2007. The Aral Sea Disaster. In: Annual Revue of Earth and Planetary Sciences [online]. Kalamazoo: Michigan. Available at http://www.iml.rwth-aachen.de/elearning/srw/uebungsmaterial/AralSeaDisaster.pdf (accesed on 3 March 2013).

Mirabdullayev I. M, Joldasova I. M, Zuri A. M, Kazakhbayev S, Lyubimova A. S, Tashmukhamedov A. B. 2004. Succesion of the Ecosystem of the Aral Sea during its transition from oligohaline to polyhaline water body. Journal of Marine Systems, 47 (4): 101-107.

Musser K. 2011. Map of the Ob river Watershed: At confluence with Irtysch River [online]. USGS. Available at http://store.usgs.gov/b2c_usgs/usgs/maplocator/(ctype=areaDetails&xcm=r3standardpitrex_prd&carea=%24ROOT&layout=6_1_61_48&uiarea=2)/.do (accesed 1 November 2012).

NASA. 2009. NASA official: Looking at Earth [online]. Washington, D. C.: NASA. Available at http://www.nasa.gov/topics/earth/features/fluxGallery/Aral_Sea.html (accesed 12 March 2013).

NASA. 2013. NASA official: Landsat Then and Now [online]. Washington, D. C.: NASA. Available at http://landsat.gsfc.nasa.gov/ (Accesed 17 March 2013).

Nečas E. 2009. Obecná patologická fyziologie. Praha. Karolinum, 377 pp.

Povýšil C, Šteiner I, Dušek P. 2007. Speciální patologie: Druhé, doplněné a přepracované vydání. Praha. Galén, 430 str.

Rakhmatullaev S, Kazbekov J, Le Coustumer P, Jumanov J, El-Oifi B, Motelica-Heino M, Hrkal Z. 2009. Groundwater resources use and management in the Amu Darya River Basin (Central Asia). In: Environmental Earth Sciences [online]. Available at http://hal.archives-ouvertes.fr/docs/00/44/29/03/PDF/manuscript_text_Amu_Darya-1.pdf (accesed on 28 March 2013).

Šobr M. 2009. Stojaté vody Asie. Disertation thesis. Charles University in Prague. Prague.

UNEP. 2006. Tajikistan: State of the Environment 2005. United Nations Environment Programme, 115 pp.

UNESCO. 2009. Water in a Changing World. The United Nations World Water Development Report 3. UNESCO, Paris and Earthscan, London, 318 pp.

UniMaps.com. 2005. Internet Information Service [online]. Available at http://coedpages.uncc.edu/theafner/Aral%20Sea/location.htm (accesed 1 April 2013).

URI: University of Rhode Island. 2001. Discovery of estuarine environments: Estuarine environments, Salinity [online]. Rhode Island: New England. Available at http://omp.gso.uri.edu/ompweb/doee/science/physical/chsal1.htm (accesed on 23 March 20013).

Viviroli D, Weingartner R. 2004. The hydrological significance of mountains: from regional to global scale. In: Hydrol. Earth Syst. Sci. [online] Bern: Switzerland. Available at http://www.hydrol-earth-syst-sci.net/8/1017/2004/hess-8-1017-2004.html (accesed on 14 March 2013).

Vohlídal J, Štulík K, Julák A. 1999. Chemické a analytické tabulky. Praha. Grada Publishing, 647 pp.

Water Rhapsody. 2011. Peace in Central Asia may Depend on Shared Water Resources [online]. Cape Town: South Africa. Available at http://www.savingwater.co.za/tag/amu-darya/ (accesed on 28 March 2013).

WHO. 2006. Guidelines for Drinking-water Quality: First Addendum to Third Edition [online]. Geneva: WHO Press. Available at http://http://www.who.int/water_sanitation_health/dwq/gdwq0506.pdf (accessed on 10 August 2013).