Effect of Khartoum City for Water Quality of the River Nile

Changes of Water Quality along the River Nile

BY

❖ OMER ABDALRAHIM BASTAWY MOHAMMED

SUPERVISOR

❖ SUSANNE JONSSON

LINKÖPINGS UNIVERSITET

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Abstract

This thesis assesses the water quality of the River Nile around the city Khartoum in Khartoum State, Sudan Republic, and investigates eventual influences of the city on the River Nile by analysis of the following parameters: temperature, pH, and conductivity, and Adsorbable Organic Halogen (AOX), cadmium (Cd), lead (Pb), chromium (Cr), Total Organic Carbon (TOC) and Nitrate (NO$_3^-$). A survey of the area is also included. It was concluded that the city Khartoum added small but legible concentrations of cadmium, lead, chromium and TOC to the river Nile. However, the resulting concentrations were all within acceptable levels. Also, the observed results showed that the Blue and White Nile, which merge together upstream on the outskirts of Khartoum, had concentrations of AOX resp. chromium, which were not suitable for drinking water.
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**Introduction**

Water is essential for life on earth. Because of the importance of water, the pattern of human settlement throughout history has often been determined by its availability. The fertile river valleys abundant water represents the beginning of civilizations. With growth, demand for water has increased dramatically, and its uses have become much more varied as used in agriculture, industry, recreation, and non-ingested personal consumption. Frequently, each of these uses required a different level of quality in order for the water to be considered adequate.

Water are exposed to innumerous natural and/or anthropogenic influence in the form of for example, sulfides; sodium chloride; metals e.g iron and toxic metals e.g. lead, cadmium and chromium; carbon components; pathogens, such as bacteria and viruses (Ali, 1999). These could be harmful to the human when high concentrations are found. The sources of water pollution is determined where human activities continue to influence the environment, which include farming, harvesting trees, constructing building and roadways, mining and disposing of liquid (Ali, 1999). With intensive agriculture, the leaching of nutrients and pesticides into the water supply may cause additional problems. There is also a growing concern of pollution caused by the leaching of industrial wastes into the aquifers.

It is important to understand that pollution can be defined in many ways, and the specific definition used in specific case can be important. For example, if an industry spewing forth contaminates to water can convince the public and the regular agencies that by their definition they are not polluting. Pressure to force them to clean up might never materialize, even though the results of inadequate waste disposal are obvious (Aarne, and Jeffery 1983). Aarne, and Jeffery (1983) stated that “Citizen has an inherent right to the enjoyment of pure and uncontaminated air and water and soil; that this right should be regarded as belong to the whole community and that no one should be allowed to trespass upon it by carelessness or his avarice his ignorance”.

The city Khartoum is the first large city, which is passed by the River Nile. Therefore it is important to know the impact of this city on the water quality of the river and how this impact might change when the river have passed through the city.
Aim
The aim of this study was to assess the water quality in the capital city Khartoum and investigate to what degree the capital city influence the water quality of the Nile River. Relevant questions were:

- Are the concentrations of the investigated parameters found in Khartoum’s river within the acceptable concentrations for the drinking water?
- Do the concentrations found in Khartoum’s river water originate from the upstream water? or
- Do they have other sources?

More precisely,
- How much do the White and Blue Niles contribute and how much is Khartoum responsible for?

To answer these questions the following analyses were performed on water samples from five different locations along the river system in Khartoum:

1. Temperature
2. Conductivity
3. pH
4. The heavy metals lead (Pb), chromium (Cr) and cadmium (Cd)
5. Adsorbable organic halogens (AOX)
6. Total organic carbon (TOC)
7. Nitrate, Phosphate, and Sulphate

The observed results are compared with the literature and the findings are discussed.

Background

The river Nile
The name of the Nile originates from the Greek word "Nelios", meaning River Valley. The River Nile is the longest river in the world (Table 1) and it is a source of life to millions of people, flowing 6.825 km (4.238 miles) from south to north over 35° of latitude through civilization of great antiquity, and the Nile basin embraces nearly 3.2 km² of the equatorial and north east Africa.
The Nile water is derived from rainfall generating the two rivers, namely the Blue Nile and the White Nile coming from two major areas: the Ethiopian Plateau and the mountainous hinterland of the Great Lakes in Uganda, respectively (Figure 1. River Nile).

The Blue Nile, which is known as Aabbay in Ethiopia, has its source at Lake Tana (3.100 km²). The lake is located in north western Ethiopia lying nearly 1.800 meter above sea level and 1.500 kilometers upstream from Khartoum. The Blue Nile drops about 410 meters and picks up the flow of two seasonal tributaries, the Dinder and Rahad Rivers (Collins1900-1988). During flooding it also carries large quantities of silt from the highlands of Ethiopia (El-Khodari, 2003).

Figure 1. River Nile

From its major source, Lake Victoria, a body of fresh water of 69.485 km² (27.000 square miles) in surface and one of the largest freshwater lakes of the world (Figure 2) the white Nile
flows northwards through Uganda and into Sudan (Collins 1900-1988). The annual flow for the White Nile at varies between 20 and 22 billion cubic meters (El-Khodari, 2003). The White Nile has a much lower gradient that the Blue Nile and consequently its terraces rise far more gently (Figure 2; Shakesby, 1991).

At Khartoum, the Blue Nile and the White Nile merge into the single river. From downstream Khartoum, the river is called River Nile. Also, 320 km north of Khartoum, they joined by the seasonal Atbara river that rises in the Ethiopian highland (Figure 1. River Nile).

The Blue Nile and the Atbara are subject to heavy seasonal fluctuations in flow as a result of the seasonal rains of the Ethiopian highlands. Between the months of July and September, flow increases dramatically due to heavy rains, but the Blue Nile may run empty during dry seasons or droughts.

Within the southern section between Aswan and Khartoum, at land which is called Nubian, the River passes through formations of hard igneous rock, resulting in a series of rapids, or cataracts, which form a natural boundary to the north. The Nile receives no additional water during the rest of its 3,000 km journey through the desert before it ends up in the Mediterranean Sea.

![Figure 2. Profile of the Nile River from lake Victoria to the Mediterranean Sea (from Waterbury, J. (1979).)](image)
The Nile River has an annual flow in normal years of 84 billion cubic meters at Aswan, in southern Egypt. Of this, 59% from the Blue Nile (NRD, 2006), and the other 41% from white Nile and Atbara and other small tributaries, which it means the Blue Nile contributes more than half of all Nile water throughout the year.

The Nile is of great importance for the population because Nile is the main source of drinking water for all those who live within these countries and it is a primary source of soil formation, which extends the hip and is transferred from the Ethiopian mountains during the flooding season, and benefited rights in agriculture.

But factors like the rapidly growing population combined with the ecological consequences, and the increasing agricultural and industrial development, which demands more and more water, are problems facing the Nile water (Waterbury, 1979).

**Khartoum city**

The major cities that are located on the edge of the River Nile system are from upstream to downstream: Juba, Damazin, Wad Madani, Khartoum, Aswan, Luxor, Cairo, and the town Alexandria which lies near the Rozeta branch. The city Khartoum is chosen for this study not only because it is the capital of Sudan and therefore most probably expecting a impacts on the river water quality, but also located in the point of meeting for the main two Rivers Blue and White Nile.

Khartoum is located at the confluence of the White and Blue Niles at 370 meters above sea level (Collins 1900-1988). It is situated between latitudes 15°26’ and 15°45’N and longitudes 32°25’ and 32°40’E. The terrain in this region is generally flat or gently sloping; only interrupted by occasional hills of rocky outcrops while sand dunes provide a gently undulating topography. This flat landscape is also broken by the floors and terraces of the Nile valleys.

**Population**

The population density in Sudan was 14.6 people/km² in 1955 and 22.7 in 1970 but declined to 14.8 in 1980 rising slightly to 16.0 in 1998 (Ali, and Ahmed, 1997). This declining trend is indicative of the large areas progressively occupied, legally as a result of planning, replanting and resettle-mint programmers, and in an unauthorized way by new migrants and land speculators. During the same period the city’s population grew from 245,000 in 1955/56 to 784,000 in 1973, 1,343,000 in 1983 and almost 3 million at the last (1993) census.
Omdurman (the west part of Khartoum) is the most populous part of the city, housing 43.5% of total population, but with the lowest numbers of people per household (Ali, 1999). In fact, 66% of the population of Sudan lived within 300 kilometers of Khartoum. In 1990 the population of the Three Towns (Khartoum, Omdurman, and Khartoum North) was unknown because of the constant influx of refugees, but estimates of 3 million, well over half the urban dwellers in Sudan, may not have been unrealistic. According to 2004 census there was about six million people living in the city Khartoum and Sudan’s current total population was around thirty five million people.

Pollution
For thousands of years, the people of Sudan have been depended on the Nile's water for survival since it is the main drinking water source in Sudan. One of the main environmental problems in Sudan is the problem with water pollution. This is particularly truth for Khartoum more than in any other city along the river, because Khartoum is the biggest city in Sudan and has the biggest population. The increasing number of citizens has certainly increased the sanitation problem (Ali, 1999); which, in turn, contributes directly to the quality of the Nile water as no treatment of the sanitation water is performed (El-Khodari, 2003).

Due to population growth in Khartoum and the parallel increasing anthropogenic activities, water pollution is increasing over time and facing an increasing problem (Ali, 1999). Polluted effluents discharged to the water system derive from several sources. One of the major sources is the disposal of untreated or semi-treated domestic effluents into water bodies. Excessive use of fertilizers and pesticides is another major source of water pollution despite the success in considerable reduction of the use of agro-chemicals during the past decade. Additionally, many of the industrial establishments do not comply with the law, which means that they dump their wastewater untreated into surface water bodies as well as inject it into groundwater.

There are many factories in the city of Khartoum that have impacts directly or indirectly on the River Nile, such as clay pits, i.e. industries for manufacture of building blocks, spread along the bank of the Blue Nile for more than 50 kilometres. The clay pits produce a lot of carbon dioxide generated from combustion of mud and outputs.
Another source of pollutants is the use of chlorine gas, i.e., disinfection of water and bleaching processes. The chlorine gas is soluble in water due to the formation of a mixture of hypochlorous acid and hydrochloric acid, according to:

\[ \text{Cl}_2 + \text{H}_2\text{O} = \text{HOCl} + \text{HCl} \]

The hydrochloric acid is completely dissolved in water to chloride and a proton, of which the latter contribute to water’s acidity. Also, the chlorine compounds are effective chlorinators of natural organic matter present in the water and carcinogenic trihalomethanes and organochlorines may be formed (WEF and ASCE, 1991). However, also the residual chlorine is toxic to many kinds of aquatic life (Mattice and Zittel, 1976). The chlorine compounds may cause chronic diarrhea, which is more deployed in areas close to the Blue Nile in Khartoum (UNMIS, 2007).

**Analysis**

**General parameters**

Physical water parameters provide information about the habitat of resident organisms. Many plants and animals have preferences or requirements regarding water temperature, salinity, dissolved oxygen concentrations, turbidity (water clarity) and pH. In this study, the parameters pH, temperature and conductivity was included.

**Temperature**

Temperature is an important parameter that regulates dissolution of gases such as carbon dioxide and oxygen. Rates and levels of chemical reactions are also affected by temperature. Therefore, it also affects biological activities.

**pH**

The parameter pH is a measure of the concentration of hydrogen ions in water. Mathematically, it is represented as:

\[ \text{pH} = -\log [\text{H}^+] \]

The state of pH in natural waters primarily determines the fate of most geochemical processes like solubility, ion exchange, weathering, sorption, precipitation, and buffering capacity (Drever, 1997). A pH between 7.5 and 9 has been recommended for drinking water. However, normal lakes can naturally have a pH around 6. Acidified lakes can have a pH around 4. Unless the water is naturally acidic, a pH below 6 could harm life in the lake (Drever, 1997), since the biological life is dependent on a certain pH.
**Conductivity**

The electric conductivity, which is a measure of the ion strength in the sample, does also influence a lot of processes, such as the different state of metals and stability of colloids (Jonsson 2006). The total concentrations of dissolved metals and the electrical conductivity are in a close connection. The more salts (cations and anions) that are dissolved in the water, the higher are the value of the electric conductivity. The majority of metals, which remain in the water after a sand filter, are dissolved ions. Sodium chloride for example, is found in water as Na\(^+\) and Cl\(^-\). High purity water that in the ideal case contains only H\(_2\)O without salts or minerals has a very low electrical conductivity. The water temperature affects the electric conductivity so that its value increases from 2 up to 3 % per 1 degree Celsius (Lenntech, 1998-2006).

**Adsorbable organic halogen analysis (AOX)**

AOX is the sum parameter of water soluble “adsorbable” organic halogens” in which _A stands for adsorbable, _O_ for organic and _X_ for the halogens chlorine, bromine and iodine. AOX can be both biologically and anthropogenic produced (Gribble, 2003). Naturally produced compounds range from simple C\(_1\)-compounds to more complex substances of about 30 carbons (Figure 3).

![Figure 3 Example AOX components (Jonsson, 2006).](image)

The group parameter AOX is widely used to survey the total amount of organically bound halogens in wastewater, drinking water and different types of natural waters (Jonsson, 2006). AOX can be found in plants, animals and humans and many other different sources like biomass fire, volcanoes and other geothermal process. The natural sources for AOX in oceans are marine plants, animals and bacteria; the water is a big source of adsorbable organic halogens (Gribble, 2003). AOX compounds discharge to the environment from selected sites and may show significant threat on human beings and biota present in the receiving areas, because many organohalogens are carcinogenic, mutagenic, long lasting and can break down into daughter
products, or further complex posing new danger to human and animal life (Asplund and Grimvall, 1991).

Large quantities of organohalogens are industrially produced and used as e.g. pesticides, disinfectants, solvents, pharmaceuticals and flame retardants. In several industrial processes and during drinking water treatment organohalogens are produced as unwanted by-products. (Asplund and Grimvall 1991), such as chlorophenols found in bleach craft mill effluents.

**Heavy metals**
Natural water contains different concentrations of metals. Some of the different states are soluble in water while others exist in the solid phase. The total concentration of metals in any natural water is the summation of soluble metals and insoluble metals or metals bound to colloids (Drever, 1997). Toxic metals, including "heavy metals" are individual metals and metal compounds that negatively affect people's health. However, some metals are necessary in small amount to support life, although in larger amounts, they become toxic.
Environmentally, heavy metals are of great concern. They are toxic to the all-living beings. They are often discharged through the industrial and urban wastes into the water. Once present in water or soil, it is difficult to get rid of them (Connell, 1999).

**Chromium (Cr)**
Chromium is a transition element located in group VI the periodic table and the most toxic form, the hexavalent Cr(VI), is usually associated with oxygen to form the chromate ($\text{CrO}_4^{2-}$) or dichromate ($\text{Cr}_2\text{O}_7^{2-}$); (Randy et al. 2006). The abundance of chromium in the earth’s crust ranges from 100 to 300 mg/g. However, several industrial processes, including leather tanning and the production of refractory steel have converted it in a serious pollutant of air, soil and water (Randy et al. 2006). Cr (VI) is a priority pollutant and has been documented to be harmful to fauna; flora and human beings and chromium-containing water and wastewater are hazardous. Removal of Cr (VI) can be done by adsorption on a non-toxic natural substance (Sharma, Weng, 2006).

**Lead (Pb)**
Lead is a metal that has been used for a long period of time, for example in batteries, ammunition and alloying elements. The metal can cause toxic effects in humans and animals and is also an inhibitory substance for microbiological degradation processes. Also, it is one
of the most common metals related to workplace illness. Lead is neurotoxin and even small amounts can be harmful, especially to infants, young children and pregnant women. Symptoms of long-term exposure to lower lead levels may be less noticeable but are still serious. Anemia is common and damage to the nervous system may cause impaired mental function (Bastawy and others, 2006). The metal enters the human body by food, water, and air. Lead can be introduced in drinking water through corrosion of water pipes when water becomes more acidic. Therefore, lead dissolved due to this acidity and into drinking water. Also, lead can enter drinking water when it sits for longer periods (longer than six hours) in household plumbing that contains lead (Bastawy et al. 2006).

**Cadmium**

Cadmium is an extremely toxic metal commonly found in industrial workplaces, particularly where ore is being processed or smelted. Exposure to cadmium can cause a number of harmful health effects due to the ability to induce disturbances in several organs and tissues following either acute or chronic exposure (Marisela, 2006). Consumption of food or drinking water with high levels of cadmium can severely irritate or bother the stomach and cause vomiting and diarrhoea. Breathing high doses of cadmium can damage the lungs and can cause death. We get cadmium in our body by breathing, eating, or drinking the substance or by skin contact (Bastawy et al. 2006).

**Nitrite and nitrate**

Anions play important roles in biological, chemical and environmental processes. Thus, the design and synthesis of molecular receptors with the ability to selectively bind anions and provide a quantifiable physical response is a rapidly growing area of interest.

In this study, the anions nitrite and nitrate were determined as a sum parameter. Nitrate is, together with phosphate, the main ingredient in fertilizers but can also come from sewage water. Nitrate, is potentially harmful if its concentration is high in water and serve as a good indicator of chemical polluted water (Peter, 1998). High concentrations have a harmful effect on living organisms (Peter, 1998). Ingestion of nitrite, e.g. through nitrate preserved meet, can pose great risk to public health by transformation to nitrosamines, which are carcinogenic (Huang et al, 1996). Since nitrate and nitrate are nutrients, there presence in high
concentrations can nurture the growth of algae in the water and consequentially impair the water quality (Bastawy et al, 2006).

**Total Organic Carbon (TOC)**
The parameter TOC (Total Organic Carbon) is often used as a non-specific indicator of water quality. Contaminations of TOC can origin from not only natural organic substances, but also anthropogenic ones such as insecticides, herbicides, and other agricultural chemicals, which enter the water body via rivers, streams or from rainfall runoff. Domestic and industrial wastewaters also contribute with organic material in various amounts. As a result of accidental spills or leaks, industrial organic wastes may enter streams, some of the contaminants may not be completely removed by treatment processes; therefore, they could become a problem for drinking water sources. Therefore, it is important to know the amount of organic carbon in a freshwater.

The larger organic content, the more oxygen is consumed. A high organic content means an increase in the growth of microorganisms, which contribute to the depletion of oxygen supplies. Generally, the content of organic material in surface waters is 5-30 mg TOC/L (Drever, 1997).

The activity of TOC influences which forms metals are present and what characteristics they have. Also, TOC have an important influence on the pH-value in certain waters, i.e. where the humic material, and not the carbonate buffer, is the dominant species (Jonsson, 2006).
Materials and methods

Sampling
In order to assess the water quality in the Nile River at the Khartoum city area, collection of samples and chemical analysis were required. Samples from the White Nile and Blue Nile were collected before entering Khartoum is at a distance of approximately 5 km before Khartoum, in order to ensure that there is no impact of these samples by the city. The next step was to perform sampling at a location where the river exits the capital city. Here, the samples will contain not only elements that came with the original river before entering Khartoum but also amounts added from activities in Khartoum.

Cleaning the bottles
Trace analysis of metals require ultra clean sampling bottles and certain precautions have to be made to avoid contamination. Fifteen polyethylene plastic bottles of 200 and 400 ml size were prepared: three bottles for each sampling point. The bottles were washed with warm acid in the micro wave. The warm acid solution was prepared by filling the bottles with milli-Q water and concentrated HNO₃ (supra pur quality) to the concentration 2 mL HNO₃ per liter water (Boutron, 1990). The bottles were covered by a plastic bag to avoid spill in the microwave and heated to ≈ 70°C in a micro wave. Then, they were rinsed in Milli-Q water three times and put in plastic bags until time of sampling.

Sampling strategy
Five water samples were collected from different points outside and within the Khartoum city (Figure 1). The samples were chosen as the following:
1. Blue Nile≈ 5 km before the river enters Khartoum city.
2. White Nile ≈5 km before the river enters Khartoum city.
3. Meeting point where the Blue and White Nile join together.
4. In the center of the City, ≈1 km after the meeting point.
5. ≈5 km after the Nile exit the city Khartoum.

The choice of sampling places has been steered by the importance of not only assessing the water quality at two different places but also to investigate any possible influence coming from the industrial zone at the other side of the channel (Figure 4 the different sampling points in the Khartoum city.).
Sampling point number [1] was chosen because its location before the Blue Nile enters the city, which let know the concentrations originating from the Blue Nile. Sample number [2] is the corresponding location for the White Nile before it enters the city. Here, the originating concentrations from the White Nile are determined.

![Image of different sampling points in Khartoum city](image)

**Figure 4** the different sampling points in the Khartoum city.

Sampling point number [3] was located in the point when the Blue and White Nile joined together. Here, it was expected that dilution of many substances took place due to higher concentration in one of the rivers and smaller in the other. Point number [4] was in the middle of the city after the White and Blue Rivers are merged together. At this point, the mixing and dilution was supposed to have attained equilibrium. Sampling point number [5] was located downstream the city, i.e. north of the Khartoum. Here, after the River’s exit from the city, where will know if the city has contributed with the targets to the Nile or not.

**Sampling and storage**

All samples were taken from the surface water in December 2006. Water from the sampling points [1], [2] and [5] were sampled approximately 1.5 m from the waterfront, and in the cases of meeting point [3] and after 1 km [4], the samples were taken from the middle of the
river from piers of one side of the river bank. The later sampling assumed more representing samples of the mixture of the two rivers White and Blue Nile. Also, influence of the river banks would be at a minimum.

The sampling procedure was as follows: After settling of disturbed sediment, the bottles were washed once with the sample. Then, the bottles were filled with the sample and closed below the water surface to make sure that the bottles were filled totally without any air. The bottles containing the samples were then placed in their plastic bags and stored at normal room temperature $\approx 20$ at that time until time of transport.

During the flight from Sudan to Sweden (two days after sampling), the samples were placed inside a bag that was tightened with a minimum of air space. No preservation such as cooling.

The water dedicated for the metal analysis were acidified immediately when they arrived to the laboratory by adding 1 mL nitric acid (1000 ml sample + 5 ml 50% nitric acid) to each bottle. By doing this, the samples were conserved and unwanted reactions were avoided (ISO 5667). Then all the bottles were kept sealed and refrigerated at 4°C until the time of analysis (APHA, 2000).

**The analyses**

**Temperature**

Temperature is a simple but useful measurement to include in a sampling regime. Methods for temperature measurement in the field and laboratory are described in standard methods (APHA, 2000). In this case, the temperature measured in the field while the samples were collecting by using thermometer, scale 0.1°C.

**pH measurement**

It is important to determine the pH immediately or as soon as possible after sampling, because pH of the natural water may change due to biochemical processes taking place in the water. The methods for measuring pH can be done with or without stirring and it can be in the laboratory (room temperature) or in the field, which means at the sampling temperature. In this case, the samples were measured without stirring at room temperature to minimize gas exchange with the atmosphere. The measurements took place at room temperature for the reason that the signal stabilizes faster than it would have done at low temperature.
measurements. A combination electrode was used in combination with a pH-meter (Combination electrode) Buffer solutions pH 4 and pH 7 were used for calibration.

**Conductivity**

An alternate current electrode was used to measure electric conductivity at 25.0ºC, since this is the reference temperature for this method (Budnikov et al, 1962). Replicate measures were performed for each sample.

**Ions**

The target ions in this project were nitrate (NO$_3^-$) and nitrite (NO$_2^-$), which were measured as a sum parameter. The instrument used was an Auto Analyser (Bran-Luebbe, model 3) using a special flow technique called "continuous flow analysis". The samples were filtered through a 0.45 µm polycarbonate filter prior injection into the instrument. The purpose of the filtration procedure was to remove sediment and other particulate matter. The sample vial was rinsed three times with MilliQ-water and one time with the filtrated sample before being filled with filtrated sample. The sample was automatically withdrawn from its vial and mixed with a reagent generating a colored nitrite complex, which was detected spectrophotometrically.

**Heavy metals**

Atomic absorption spectroscopy (AAS), a single beam instrument (Perkin-Elmer 1100) with a graphite furnace (HGA-500) and a sample exchanger (AS-40) was used to determine the presence (quality) and concentration (quantity) of the metals lead (Pb), cadmium (Cd) and chromium (Cr). The samples were atomized in a graphite furnace, which has lower detection limits compared to flame atomization (AAS, 2007). AAS works on the principles of atomizing a sample and quantitatively determine the concentration of atoms in the gas phase by measuring the intensity of light absorbed by the elements. The basic principle is that the compounds atomises by the heat and absorb light with a specific wavelength This light intensity can be measured in a photo-multiplier. In this way the concentration of the metal can be determined (Harris, 2006). The signal from the detector is transferred to the computer. Required adjustments were made according to the manual.

Calibration curves were made by using three different solutions of known concentrations: 0.2, 0.5, 0.1 ppb for cadmium, 1.25, 2.5, 6.25 ppb for lead, and 1.0, 5.0, 10.0 ppb for chromium. The computer generates a graph corresponding to linear equation derived from the readings of calibration solutions.
The samples were injected into the instrument. More precisely, 40 µL was injected for lead and cadmium analyses and 80 µL for chromium. These volumes were chosen depending upon the concentrations of the metals that was expected after a rough screening of the samples. The different temperatures used for drying, combustion and atomizing the samples were depended on the metal and type of graphite tube used. The samples were first dried at approximately 100-120°C. During the second step, combustion of the sample, the temperature was increased to 700-1000°C. The temperature should be high enough for total combustion of the matrix without atomization of the element, which means that thermo labile compounds vaporized and organic compounds degraded. The third step included atomization of the residuals at a very high temperature (2100°C for lead and cadmium, and 2600 for chromium), during a short time period. In this way, the largest amount of excited atoms as possible was achieved in the graphite tube (Figure 5). To avoid cross contamination, a fourth combustion step was performed at 2650°C.

![Figure 5. General atomization of elements analysis by atomic adsorption spectrometry (AAS).](image)

**Adsorbable organic halogens (AOX)**
EUROGLAS developed to measure the organic halogens in extracts, samples of primarily wastewater. This is one of the easiest and quickest methods to analyze the organic halogens...
present in water samples. The standard method was applied and an AOX-analyser (Euroglas, model 84/85) was used for the analyses.

The theory behind the method is as follows:
The organic content in the water sample is adsorbed onto activated carbon. Complete sorption is achieved by lowering the pH by HNO₃, which assure protonisation of acid compounds. The filtrated (0.45 µm polycarbonate filter) sample is injected into the instrument and heated to 1000°C in presence of oxygen and all organic material is completely combusted. The carbon is oxidized to carbon dioxide, and hydrogen to water. The halogen is transformed to HX and transported to an electrolyte were it is automatically titrated by microcoulometric titration with two silver electrodes. The halogens detected are chlorine and to some extent bromine and iodine, if such ions are present.

The following calculation was made:
\[
[AOX] = \frac{(N - N₀) \times M}{V \times F}
\]

N = the observed value in Coulomb
N₀ = blank value in Coulomb
V = volume of sample (L)
M = molecular weight of chloride, i.e. 35.45 g/mol
F = Faraday’s constant, i.e. 96 487 Coulombs/mol

**Total organic carbon (TOC)**
The standard method 5310B (Combustion) was applied on a Shimadzu 5000-TOC instrument for the analysis of the amount of carbon in the samples. This was done by measuring the amount of CO₂ that was produced by combustion of the organic material at 680°C giving the total carbon (TC). The inorganic carbon (IC) present in the sample was transformed to CO₂ by acidification with phosphoric acid (H₃PO₄) without passing the oven. The amount of organic carbon present in the sample was determined by a mathematical calculation, i.e. the difference between TC and IC:

\[
TOC = TC - IC
\]
The detection limit of Shimadzu's TOC 5000 combustion oxidation instruments was 0.5-20 ppb. The Shimadzu TOC-5000 instruments was well suited for this study since it according to the manufacturer is capable of performing analysis on any high sensitivity applications such as pharmaceutical grade, semiconductor grade, steam power, and ultra pure waters, as well as less sensitive application such as drinking water and particulate analysis such as wastewater and industrial effluents, sea water, brines, ground water, and surface water (Shimadzu, 2007). The samples were injected by an auto sampler, i.e. 200 µL was injected for TC and 20 µL for IC analysis. The measurements were performed in duplicates and reported with a standard deviation of less than 20%. A standard solution of 10 ppm C was used to check the chosen calibration curve.
Results and discussion

Complementary analyses and statistics show that there are two types of waters that come to the River Nile via White and Blue Nile. The waters have different concentrations and different flows are mixed together at the meeting point, which lead to fluctuating concentrations along the transportation through Khartoum city, trying to get to the equilibrium states. As the Blue Nile contributes with approx. 60% of the water volume to the River Nile it consequently affects the concentrations observed in the mixed Nile water. The opposite is not that pronounced. The most obvious differences between the two rivers were that the concentrations of AOX, Cd and Pb were higher in Blue Nile than White Nile, while TOC, Cr and nitrate were higher in White Nile compared to Blue Nile.

End Member Mixing Analysis (EMMA)

EMMA has been used previously for successful modeling of stream water chemistry as a mixture of end-member soil water types and to estimate the hydrologic contribution to the stream from each end-member (Donahoe, 1994)

In this study, EMMA has been applied to the results observed on White and Blue Nile. As we know, 60% to the Blue Nile and 40% to the White Nile. Other tributaries are ignored. The equation concerning the Nile River is:

\[ 0.6 C_B + 0.4 C_W = 1.0 C_E \]

\( C_B \) = Concentration of Blue Nile  
\( C_W \) = Concentration of White Nile  
\( C_E \) = Estimated concentration when the two rivers are completely mixed together (sample 5)

Temperature

The temperature was measured at the sampling area. The observed temperatures at the different sample locations were within the range. 20 and 21°C (Table 1) which it slightly higher than the recommendation limit according to Guidelines for Canadian Drinking Water Quality. But here and in this subtropical country this temperature it might be a normal temperature.
**pH**
The pH of pure water is 7. In general, water with a pH lower than 7 are considered acidic, and with a pH above 7 alkaline. The normal range for pH in surface water systems is 6.5 to 8.5, (APEC, 2007)

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Temperature °C</th>
<th>pH</th>
<th>Conductivity µS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Blue Nile</td>
<td>20</td>
<td>7.5</td>
<td>240</td>
</tr>
<tr>
<td>2. White Nile</td>
<td>20</td>
<td>8.2</td>
<td>190</td>
</tr>
<tr>
<td>3. Meeting point</td>
<td>21</td>
<td>8.0</td>
<td>190</td>
</tr>
<tr>
<td>4. One km after meeting point</td>
<td>21</td>
<td>7.8</td>
<td>240</td>
</tr>
<tr>
<td>5. After passing Khartoum City</td>
<td>20</td>
<td>7.9</td>
<td>210</td>
</tr>
</tbody>
</table>

The results from the pH measurements showed that all the samples were within the range considered normal for surface waters. However, the White Nile was more alkaline than the Blue Nile, pH 8.2, and 7.5, respectively. At the point where the two rivers merged, there was a dilution of the H⁺ concentration compared to the Blue Nile. The pH observed in the water after passing Khartoum city was 7.9 (Table 1). This is in accordance with the EMMA calculation, which report pH 7.8. The decrease of the pH from the point of river junction downstream to outside the city might have three reasons: 1) inhomogeneous mixture of the two rivers, or 2) a slow but continuing strive to reach equilibrium.

**Conductivity**
Freshly distilled water has a conductivity of 0.5–2 µS/cm, and this value increases up to about 4µS/cm due to absorption of carbon dioxide and, to a lesser extent, ammonia from the atmosphere. For surface water, the conductivity is typically within the range 50–1000 µS/cm (Dojlido, and Gerald, 1993). Some industrial waste water may have a conductivity value of several thousand µS/cm (Dojlido, and Gerald, 1993). The recommendation for drinking water quality stipulates maximum allowable value of 1500 µS/cm, whilst the recommended limit for river water for direct abstraction to supply is 1000 µS/cm (Dojlido, and Gerald, 1993).

Blue Nile had a conductivity of 240µS/cm and White Nile had 190µS/cm, (
Table 1) which show that they are within the range of typical surface waters. At the meeting point, the conductivity also was 190, which might indicate that the sample was not representative but rather more influenced by the White Nile. An indication that this might be the case is showed by the fact that the conductivity had increased to the value of the Blue Nile, i.e. 240µS/cm at the sampling point 1 km downstream the point of river junction. However, the conductivity decreased to a value averaging the two rivers after passing the city 210 µS/cm. The fluctuating value most probably has its origin in inhomogeneous mixture of the two rivers.

The conductivity value in sample [5] downstream Khartoum city was estimated according to EMMA to 220µS/cm, which is just slightly more than the observed value i.e. 210 µS/cm (Table 1).

**AOX**

The concentration of adsorbable organic halogen (AOX) in surface water is often between 10-30 µg/l. However, concentrations up to 200µg/L have been measured in non-pollutant areas (Des and Gregory, 1984). Larger AOX values most often coincide with large content of organic carbon.

The Blue Nile had a three times larger concentration of AOX than the White Nile (Table 2). The high AOX levels can come from naturally sources in forested areas (Asplund, 1992; Hjelm, 1996) and be caused by large amount of marine plants, animals or bacteria’s in the water (Gribble, 2003). However, the marine input is in this case negligible.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Concentration of (AOX) µg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Blue Nile</td>
<td>31.7 ± 6.0</td>
</tr>
<tr>
<td>2. White Nile</td>
<td>11.0 ± 2.0</td>
</tr>
<tr>
<td>3. Meeting point</td>
<td>7.5 ± 0.4</td>
</tr>
<tr>
<td>4. One km after meeting point</td>
<td>9.1 ± 1.0</td>
</tr>
<tr>
<td>5. After passing Khartoum</td>
<td>9.0 ± 0.7</td>
</tr>
</tbody>
</table>
The high AOX levels can also come from naturally sources in forested areas (Asplund, 1992; Hjelm, 1996) and be caused by large amount of marine plants, animals or bacteria’s in the water (Gribble, 2003). However, the marine input is in case negligible.

Then there was a decrease of the AOX concentration at the meeting point of the two rivers due to different flows from White and Blue Nile. The lower AOX concentration in the White Nile caused dilution of the Blue Nile giving the final concentration observed after the point of river junction. Then the concentration started to increase in the center of Khartoum to \( \approx 1.6 \) units from \( 7.5 \pm 0.4 \, \mu g/L \) in the meeting point to \( 9.1 \pm 1 \, \mu g/L \) and \( 9.0 \pm 0.7 \, \mu g/L \) after one kilometer, and after passing the city, respectively (Table 2).

Using the EMMA model, estimated concentration of AOX should be \( 23.6 \mu g/L \) at sample point 5, which is much higher than observed concentration of \( 9.0 \mu g/L \). The discrepancy can be due to precipitation of AOX to the river sediment. The importance of photooxidation is unknown but should probably not be excluded.

![Figure 6 Concentrations of adsorbable organic halogen (AOX) at the Khartoum’s Rivers given in µg/L](image)

The White Nile, the water in the meeting point and in the center of the city have relatively small AOX concentrations compared to the normal range referred to above. The Blue Nile had three times higher concentration of organic halogens; it was slightly higher than recommended limit. The city Khartoum does not seem to contribute or add AOX to the River Nile (Figure 6).
**Total Organic Carbon (TOC)**
Together with total organic carbon (TOC), the total carbon (TC) and inorganic carbon (IC) were analyzed. The determination of total organic carbon is accomplished by subtracting the measured inorganic carbon from the measured total carbon. The results are presented in (Table 3).

The TOC concentration in the White Nile was 9.0 mg/L, which was higher than Blue Nile, which was 5.9 mg/L. The concentrations of IC was relatively high compared to TC, which means that carbonates was the main contributor to the carbon content in the water.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>TC mg/L</th>
<th>IC mg/L</th>
<th>TOC mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Blue Nile</td>
<td>30</td>
<td>24</td>
<td>5.9</td>
</tr>
<tr>
<td>2. White Nile</td>
<td>28</td>
<td>19</td>
<td>9.0</td>
</tr>
<tr>
<td>3. Meeting point</td>
<td>28</td>
<td>18</td>
<td>10.0</td>
</tr>
<tr>
<td>4. one km after meeting point</td>
<td>29</td>
<td>24</td>
<td>5.8</td>
</tr>
<tr>
<td>5. After passing Khartoum</td>
<td>29</td>
<td>21</td>
<td>7.4</td>
</tr>
</tbody>
</table>

The primary source of the observed TOC is probably the residuals from naturally occurring plant material. Under natural conditions the leaves, stems, and roots of trees, shrubs, grasses, and other native plants supply large quantities of organic residues to aquatic systems in the south of Sudan, where the river has its origin, because this region is very rich of vegetation. Also, TOC could be resulting from the huge amount of animals in the southern Sudan. The animals are usually considered as a secondary source of TOC (Brady, 1984). As they attack the original plant tissues, they contribute to waste products and leave their own bodies as their life cycles end. Certain forms of animal life, especially the earthworms, centipedes and ants, also play an important role in the translocation of plant residues (Brady, 1984).

Southern Sudan is a very poor region due to long periods of war and the life there is traditional. There is no water drainage system, sewage is not treated therefore the runoff carries the wastewaters to the river and contribute to the TOC.

TOC concentration were 10 mg/L at the point where the Blue and White Nile joined together. The small additional concentration might be from the city. More precisely, it is possible that small the agriculture fields belonging to the Khartoum city might contribute with TOC.
After one km, when the two flows are assumed to be totally mixed, the TOC concentration decreased 4 TOC units, i.e. from 10mg/L to 6mg/L, which was the same level as the one observed in the Blue Nile. It can not be confirmed nor excluded that the increased concentration 7µg/L observed after Khartoum is a contribution from city activities.

Comparison of the of the TOC concentration observed in sample [5], i.e. 7.4mg/L, with the concentration estimated by EMMA, i.e. 7.5mg/L, show that the measured value is within the expected range.

In general the concentrations of IC were much higher than TOC in all the sampling points (Figure 7). TC concentrations were approximately the same in the all sampling points (28-30 mg/L). However differences were found among the IC and TOC concentrations (Table 3 and Figure 7).

According to Drever (1997) rivers generally have dissolved organic carbon (DOC) contents of 2-15 mg/L, while rivers draining swamps and wetlands can have DOC contents of 5-60 mg/L.
Since I have measured TOC, i.e. DOC + POC (particulate organic carbon), the White and Blue Nile and the main river have concentrations within the expected range.

**Heavy Metals**
The results presented in (Table 4) represent the detected concentration of the metals cadmium, lead and chromium in the five different sampling locations. Detailed observations of each metal are given below.

<table>
<thead>
<tr>
<th>Sampling number</th>
<th>Cadmium (Cd µg/L)</th>
<th>Lead (Pb µg/L)</th>
<th>Chromium (Cr µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Blue Nile</td>
<td>0.008±0.02</td>
<td>0.5±0.1</td>
<td>0.6±0.1</td>
</tr>
<tr>
<td>2. White Nile</td>
<td>0.002±0.03</td>
<td>&lt;0.1</td>
<td>6.6±0.5</td>
</tr>
<tr>
<td>3. Meeting point</td>
<td>&lt;0.001</td>
<td>0.4±0.1</td>
<td>4.1±0.2</td>
</tr>
<tr>
<td>4. One km after meeting point</td>
<td>&lt;0.001</td>
<td>&lt;0.1</td>
<td>0.6±0.1</td>
</tr>
<tr>
<td>5. After passing Khartoum</td>
<td>0.03±0.01</td>
<td>0.2±0.1</td>
<td>3.9±0.2</td>
</tr>
</tbody>
</table>

**Cadmium**
The concentration of cadmium in Blue Nile was 400% higher than observed in White Nile. The level observed in Blue Nile might be the result from industrial activities along the river (see Introduction), or it can be the result from the fact that population living along the Blue Nile is higher compared to the White Nile (Ahmed, 1997).

The concentration of cadmium at the meeting point of the two rivers and at the center of Khartoum was below the detection limit (0.001µg/L) of the method used making accurate measurement at this level impossible. The decrease of the concentrations may be due to different flows when different concentrations are mixed together.

When the Blue Nile is mixed with white Nile, which has a higher concentration of carbon (Table 4), cadmium may precipitate as carbonate or adsorb onto particulate matter and incorporate into the bottom sediment (Dojlido, and Gerald, 1993) generating a lower concentration of cadmium in the water phase.

The concentration became relatively high (0.024 µg Cd/L) after the river had passed Khartoum, which indicate contribution of cadmium from the city to the Nile river (Figure 8).
EMMA estimated that the concentration resulting from mixing of White and Blue Nile should be 0.006\(\mu g/L\), This is 4 times less than the actual observed concentration i.e. 0.024\(\mu g/L\), which indicate a contribution by the city to the Nile. The additional concentration could result from anthropogenic processes such as industry, agriculture, construction, transportation, or habitation, which are all well represented in the city.

In non-polluted areas, however cadmium is either not detected or presented in concentrations up to 0.13 \(\mu g/L\) (WHO 1973), where the latter most probably refers to areas with high cadmium mineral contents. According to Guidelines for Canadian Drinking Water Quality (GCDW 2007) the maximum acceptable concentration for drinking water for cadmium is 5\(\mu g/L\). Since the Blue and White Nile and the main river Nile had comparatively low concentrations, the observed levels do not let us regard the Nile as polluted with cadmium.

**Lead**
The concentration of lead in Blue Nile was higher compared to White Nile, i.e.0.5\(\mu g/L\) and below detection limit (0.1\(\mu g/L\), respectively (Table 4). At the meeting point the concentration was 0.4\(\mu g/L\), most probably due to dilution of the Blue Nile with the smaller flow from the White Nile. Then, the dilution continued over time until the lead concentration dropped to below the detection limit in the center of the city. However, after 50 km from the
city the concentration of lead raised to 0.2µg/L, which most probable is equivalent to the addition from the city Khartoum to the River Nile (Figure 9).

The addition of this relatively small concentration of lead might originate from lead pipes as they are used when water is stored in lead lined tanks and later on transported to the household and back to the river as wastewater. Also, exhausts from vehicles might contribute to increased concentration observed downstream the city Khartoum because exhausts are regarded as the major source of environmental contamination by lead (Dojlido, and Gerald, 1993).

If we use the EMMA calculation in this case, the estimated result for a completely mixed water should be 0.3µg/L, which slightly more than what was found in sample point [5], i.e. 0.2µg/L. This indicate that there is no contribution from of the city to the Nile.

According to Guidelines for Canadian Drinking Water Quality the maximum acceptable concentration for drinking water for lead is 10µg/L. The Blue, White Nile and the River Nile had 20 times or lower concentrations compared to the standard level and would therefore not be considered as ecologically harmful.

**Chromium**

The chromium concentration in the Blue Nile was lower than that of the White Nile, 0.6 and 6.6µg/L, respectively (Table 4). The higher concentration in the White Nile might be result
from combustion of natural coal, which is the main source for energy in the southern part of Sudan. According to US Environmental Protection Agency (2007), the largest sources of chromium emission to the atmosphere are from combustion of natural gas, oil, and coal together with the chemical manufacturing industry. The gas emissions, in turn, precipitate over land and water.

The concentration of chromium decreased to 4.1µg/L at the sampling point where the White Nile mixed with the Blue Nile because of the higher water flow of the Blue Nile than of the White Nile. The concentration decreased further and was 0.6µg/L at the centre of Khartoum (one km from the meeting point where the two rivers join together).

![Concentration of Chrome (Cr)](chart.png)

**Figure 10** The chromium concentrations observed in samples from the different sampling points

Compared to the level observed at the centre of the city, the concentration of chromium increased more than six times and became 3.9µg/L after the exit of Khartoum city (Table 4 and Figure 10).

EMMA assumes that the concentration at sample point [5] should be 3µg Cr/L, which is 0.9µg/L additional amount added from the city. This addition is most probable the result from human activities in the city such as industry of leather tanning or other industrial processes that using chromium.
According to Guidelines for Canadian Drinking Water Quality the maximum acceptable concentration for drinking water for chromium is 5µg/L. The White Nile had concentration slightly higher than the acceptable concentration level of chromium and should therefore be considered as polluted.

**Ions**

As a whole, the levels of the sum parameter nitrate plus nitrite were observed below or just above the detection limit (Table 5). Since nitrate usually is the dominant ion compared to nitrite, it was decided not to analyze nitrite. Further on in the text, the sum parameter therefore is expressed as nitrate. The concentration observed in the White Nile decreased to below the detection limit at the centre of the city and this decrease could be due to absorption of nutrients (nitrate and phosphate) by plant life such as algae and plankton. This conclusion is based on the low visible depth, which is the main result of high levels of plankton and algae.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Nitrate mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Blue Nile</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>2. White Nile</td>
<td>0.011</td>
</tr>
<tr>
<td>3. Meeting point</td>
<td>0.007</td>
</tr>
<tr>
<td>4. 1 km after meeting point (Center of Khartoum)</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>5. After passing Khartoum</td>
<td>0.032</td>
</tr>
</tbody>
</table>

The nitrate concentration observed after the exit of the city most probably had its origin by city activities in Khartoum (Table 5 and Figure 11). This was clear when EMMA calculation was applied: calculations resulted in 0.002 mg/L while the observed concentration was 0.032 mg/L, which is 16 times higher than the estimated concentration. However, it should be noted that 0.03 mg/L is still very low.
Since nitrate is one of the main ingredients in fertilizer, this additional amount could be resulting from the agricultures belong the city. Also it can be from sewage water. However, it should be noted the concentrations of nitrate found in the Nile waters are very small compared to Guidelines for Canadian Drinking Water Quality, which has settled the maximum acceptable concentration for drinking water to 3.2 mg/L. This concentration is much higher than the concentrations observed in Blue, White and River Nile (Table 5).
Comparisons
Most of the studies have been focused on the main river, i.e. River Nile. Therefore, and as far as I know, it was difficult to find results regarding the White and Blue Nile to compare with, but according to Kim and Sultan (2002) the pH in the River Nile in Aswan (Egypt) was between 7-8.5, which is the same range as I found in this study (pH 7.9). Other parameters, such as AOX was 10µg/L, which also coincide with my study (9 µg/L).

According to Syed et al, (2004), the concentrations of heavy metals in the river Nile near Nasser (Egypt) were the following:
The concentration of lead was 1.03µg/l, which is much higher than that around the city Khartoum, which was 0.2µg/L. The chromium concentration was <0.05µg/L, which was much smaller compared to Khartoum City (3.9µg/L). Regarding cadmium, the concentration reported by Syed et al. was <0.05µg/L, which was approximately the same as in the present study, i.e. 0.03 µg/L.

According to Earth Sciences Remote Sensing Lab in Egypt, the concentration of nitrate in the Nile River was below 0.01mg/L, which is within the range found in the waters around Khartoum in the present study.

TOC concentration measured by Mohammed et al. (2006) in Nile water in closed areas of the Mediterranean coast of Alexandria was 6.34µg/L. which is just slightly less than the concentration I found around the city Khartoum, namely 7.4 mg/L.
The goal of this study was to assess the water quality of the River Nile along the city Khartoum and determine if the city affected the water quality. Three important tasks were required to accomplish this goal: sampling (getting fifteen samples from five different points), analyses (nine relevant and different parameters were chosen to cover a broad range of possible influencing pollutants), then finally statistical process and evaluation of the results.

The Khartoum city contributed to some extent with the following parameters to the river Nile:

- 0.024 µg/L of cadmium (Cd).
- 0.1 µg/L of lead (Pb).
- 3.3 µg/L chromium (Cr).
- 1.6 mg/L of TOC.
- 0.03 mg/L nitrate.

The water quality of Blue Nile and White Nile and the main river Nile showed pH, conductivities and temperatures within the normal ranges. The concentrations of the TOC, cadmium (Cd), lead (Pb) and nitrate (NO$_3^-$) found in surface water of the Nile River in Khartoum city were within the acceptable concentrations (Table 6).

Table 6 A summary of the observed parameters compared to the maximum acceptable concentration (MAC) reported by Guidelines for Canadian Drinking Water Quality.

<table>
<thead>
<tr>
<th>Type of analysis</th>
<th>Blue Nile (1)</th>
<th>White Nile (2)</th>
<th>Meeting point (3)</th>
<th>Centre of Khartoum (4)</th>
<th>After Khartoum city (5)</th>
<th>MAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. (°C)</td>
<td>20</td>
<td>20</td>
<td>21</td>
<td>21</td>
<td>20</td>
<td>≤15</td>
</tr>
<tr>
<td>pH</td>
<td>7.5</td>
<td>8.2</td>
<td>8.0</td>
<td>7.8</td>
<td>7.9</td>
<td>6.5-8.5</td>
</tr>
<tr>
<td>Conductivity µS/cm</td>
<td>240</td>
<td>190</td>
<td>190</td>
<td>240</td>
<td>210</td>
<td>1000</td>
</tr>
<tr>
<td>AOX (µg/L)</td>
<td>32</td>
<td>11.0</td>
<td>7.5</td>
<td>9.1</td>
<td>9.0</td>
<td>30</td>
</tr>
<tr>
<td>TOC (mg/L)</td>
<td>5.90</td>
<td>9.0</td>
<td>10.0</td>
<td>5.8</td>
<td>7.4</td>
<td>15</td>
</tr>
<tr>
<td>Cd (µg/L)</td>
<td>0.008</td>
<td>0.002</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.024</td>
<td>5</td>
</tr>
<tr>
<td>Pb (µg/L)</td>
<td>0.5</td>
<td>&lt;0.1</td>
<td>0.4</td>
<td>&lt;0.1</td>
<td>0.2</td>
<td>10</td>
</tr>
<tr>
<td>Cr (µg/L)</td>
<td>0.6</td>
<td>6.6</td>
<td>4.1</td>
<td>0.6</td>
<td>3.9</td>
<td>5</td>
</tr>
<tr>
<td>Nitrate (mg/L)</td>
<td>&lt;0.002</td>
<td>0.011</td>
<td>0.007</td>
<td>&lt;0.002</td>
<td>0.032</td>
<td>3.2</td>
</tr>
</tbody>
</table>
The AOX concentration observed in the Blue Nile, 32µg/L, was slightly higher than the recommended limit (Table 6), which conceder this area of Blue Nile as a harmful to AOX-related problems.

The concentration of chromium (Cr) in the White Nile was 32% higher than the maximum acceptable concentration for drinking water quality.

Otherwise, all other parameters showed that the rivers were within natural concentrations compared to the maximum acceptable concentrations reported by Canadian guidelines for drinking water quality. These observed concentrations are probably the result of naturally low concentrations in the river catchments.

From the summary tabulated in Table 6 it can be concluded that the capital of Sudan, Khartoum, only had no or only minor influence of the drinking water quality in the Nile River.

**Future work**

For the future work, I suggest the following:

- Several samples from the same location i.e. for the same sampling point should have at least nine samples should be divided accordingly: triplicate samples from the ≈1m from each waterfront, and triplicates from the middle of the river. By this sampling strategy, we make sure the water represents the whole area from where it was taken.

- Sampling at different occasions, i.e. to avoid unforeseen events that might happen suddenly and strongly influence sampled water. Also, natural fluctuations are covered by sequential sampling.

- By analyzing water from the house after passing the distribution lines, it might be possible to trace the source of the health problems. Also, it is useful to know and quality of the water that enters the households after purification and filtration processes performed by the water treatment plant.
- Analyze river sediment from different depths and trying to identify areas influenced by industrial activities.

- Biological analyses, such as bacteria, because of its active role in human health.

Reflections

Before I started my work I was thinking: Are my people drinking suitable water? Do they contribute and pollute the river Nile? Since I was studying water recourses I had to know that. I felt that it was my role. But what can I do to help my people?

Is it enough to see if our drinking water is suitable or not? Or should I determine from where we get the pollution, if there is any? Of course, I would prefer to locate from where the pollution comes from and prevent future pollution.

What are the important and common pollutions that might be of interest? What parameters should I analyze? By scrutinizing scientific literature and newspapers I tried to identify what problems we are facing? It was difficult to find some thing scientific about especially Khartoum, since most of the studies have considered Egypt. That made it difficult when trying to compare my observed results with the others studies.

During my experimental work I found it tricky to handle all the different instruments even though standard methods were used.

The analyses were done by the help from my supervisor Susanne Jonsson, research engineer Lena Lundman and PhD student Maritha Hörsing. They were all useful advisers in a perfect way. Thanks a lot!
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