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Simple and Appropriate Methods for Household Water Treatment

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Simple and Appropriate Methods for Household Water Treatment

By

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Abstract

Shortage of drinking water is the big challenge for Sudan. The cost of water treatment is the main reason for using untreated water for drinking purposes in many urban areas in Sudan. Water born-diseases (diarrhea, typhoid, etc) are common and there are many victims in unimproved urban areas in Khartoum (Sudan) due to poor or the lack of treatment of drinking water.

In this work, a simple and appropriate method (sand filter) for household water treatment was tested and developed. The main objective of using this method is to help people in urban areas without access to treated water to improve drinking water quality individually. Experiments were run to improve design and operating conditions for removing turbidity by sand filtration. The lowest turbidity was found to be 8 NTU from initial turbidity 2100 NTU (99.6% removal).

Nile River water characteristics data were analyzed to understand water quality in Khartoum. The water quality data were obtained from Biwater Company LTD and compared with the WHO standards for drinking water. The major water quality problem was the high turbidity which is often correlated with high levels of pathogens and other water quality impairments. Monthly histograms for the period during August 2004 to August 2005 were done to characterized temporal patterns in turbidity. Tukey's Honest Significant Difference test was used to discover that the only different between monthly averages was found to be during the Nile floods in Khartoum (July-September).

Finally, the estimated sand filter cost and medical treatment expenses for water borne illness in Khartoum were compared. The medical expenses were found to be high compared to the sand filter cost. This leads to the potential for large physical and economic benefits, and improvement in these urban areas due to using this simple method of water treatment.

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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 with abundant water represent the beginning of civilizations. With growth, demand for water has increased dramatically, and its use becomes much more varied for drinking, agriculture, industry, recreation, and non–ingested personal consumption. Frequently, each of these uses requires a different level of quality in order for the water to be considered adequate.

The shortage in potable water is an important challenge facing our world today. That is because, of a population of nearly 7 billion, more than 1 billion lack access to potable water and about 5 million people die every year from water-borne disease related to poor drinking water quality.

The main reason of this shortage in potable water is the cost. Often, even if the water sources are available, developing countries cannot cover the expense of constructing water and wastewater treatment plants, distribution systems and the cost of the treatment processes for all residents. However, investment in water and sanitation makes economic sense; the economic return of a $1 investment in sanitation is $9, the return on $1 investment in safe drinking water is $4 to $35 (WHO, 2009).

From this point of view, it is very important to find new methods that use low-cost technology for water treatment to reduce the cost and to increase the quantity and quality of potable water. One of these methods is the design of household water treatment systems that depend on the simple, well established, technology of filtration and disinfection for water treatment for individuals using easily obtained materials, to treat water in an effective and inexpensive way. In this project we will evaluate one such method (Watkins 2009) using several samples of water from the Logan River and

Spring Creek in Logan, Utah and study the effectiveness of the treatment approach on finished water characteristics. We will also study the potential impact of this method for improving the health and the economy in developing countries, using the Sudan as a case study.

Sudan is one of the developing countries in which the water treatment cost is considered to be an important and difficult challenge. Statistically studies show that 13.9 million out of Sudan's total population of 39.5 million do not have access to improved sanitation and 11.4 million have no access to improved drinking water (UNICEF, 2008). Due to this one out of four children dies in Sudan before age five from kidney failure and diarrheal diseases that are very common, (UNICEF, 2008) and are easily controlled with modern water treatment technology.

In Khartoum City, the capital of Sudan and the first large city situated on the River Nile, with population about 8 million, there is a shortage in drinking water of about 400,000 cubic meters per day in the public drinking water system (KSWC, 2008). Because of this many in the urban areas in Khartoum pay about 10% of their monthly income to buy water without any kind of treatment due to the lack of water treatment plants and a distribution system. Many of these residents live in unincorporated areas in and near Khartoum that have no public infrastructure, either due to the lack of resources or for political reasons. The current shortage argues for both short and long term solutions to providing safe drinking water. The long term solution involves the extension of water-related public services to all parts of the city and modern management of development. The short term approach is to first address the poor quality of River Nile water for drinking and then to address the high cost of the water by public control.

Objectives

The objectives of this project are outlined below. Details are provided subsequently.

1. Find, develop, and assess a simple, effective, and appropriate method for water treatment to provide safe drinking water for households in Khartoum urbanized areas at low cost. It is proposed to use and improve a simple technology method of Watkins (2009) to achieve this part of study.
2. Assess and evaluate the River Nile water characteristics in Khartoum using data analysis and compare it with WHO regulations for drinking water.
3. Clarify the benefits of applying the first objective on the human health in Khartoum. If the health situation becomes better due to treated drinking water it may be possible to improve living and economic conditions for these poor areas.

Background

1. 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 and the source of life to millions of people. It flows 6,695 km (4,160 miles) from south to north over 35° of latitude through civilizations of great antiquity; the Nile basin embraces nearly 3,254 km^2 of equatorial and north east Africa.

The Nile water derives from rainfall generating two rivers, namely the Blue Nile and the White Nile coming from two major areas: the Ethiopian plateau and the mountain hinterland of the Great Lakes in Uganda, respectively (Figure 1).

Figure 1: The White Nile, Blue Nile and Nile River.

The Blue Nile, which is known as Aabbay in Ethiopia, has its source at Lake Tana (3.10 Km^2). The lake is located in north western Ethiopia lying nearly 1.80 KM above sea level and 1500 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 (Collins 1900-1988). During flooding it also carries large quantities of silt from the highlands of Ethiopia (El-Khodari, 2003).

At Khartoum, the Blue Nile and the White Nile merge to form the River Nile. At 320 km north of Khartoum; the Nile is joined by the seasonal Atbara River that also rises in the Ethiopian highlands (Figure 1)

The Blue Nile and the Atbara rivers are subject to large flow fluctuations as a result of seasonal rains in the Ethiopian highlands. Between the months of June and September, flow increases dramatically due to heavy rains, but the Blue Nile may run dry during dry seasons. In the wet season the peak flow at the Blue Nile will often exceed 5,663 m^3/s , while in dry season the natural discharge may drop to 113 m^3/s (4,000 Cu Ft) (marshal et al, 2007). Around 59% of the Nile River water comes from the Blue Nile (Lewis, 2009).

The mean annual flow in the Nile River is around 2663 m^3/sec, which is mean, the mean annual Blue Nile flow is around 1571 m^3/sec.

From its major source, Lake Victoria, a body of fresh water of 69.5 km^2 (27.0 m square miles) in surface and one of the largest freshwater lakes of the world (Figure 1), the White Nile flows northwards through Uganda and into Sudan (Collins, 1988). The annual flow for the White Nile varies between 20 and 22 billion cubic meters (El-Khodari, 2003). The White Nile has a much lower gradient than the Blue Nile and consequently its terraces rise far more gently (Figure 1).

Within the northern Sudan section between Khartoum and Aswan in Egypt, called the Nubian region, the river Nile passes through formations of hard igneous rock, resulting from 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 3000 km journey through the Egyptian desert before flowing to the Mediterranean Sea.

The Nile has an annual average flow of 2663 m^3/sec at Aswan but is subject to significant spatial and temporal variation (FAO 1997), in southern Egypt. Of this, 59% is from the Blue Nile, and the other 41% is from White Nile and Atbara, and other smaller tributaries.

The Nile is of great importance for the population because it is the main source of drinking water for all those who live within these countries. It is also a primary source of soil formation within the entire Nile basin during the flooding season, and benefits agriculture. The Nile River is also an important resource of Sudan, where the Rosiers and Senar dams, southern of Khartoum, produce like 80% of the country's power beside irrigation purposes.

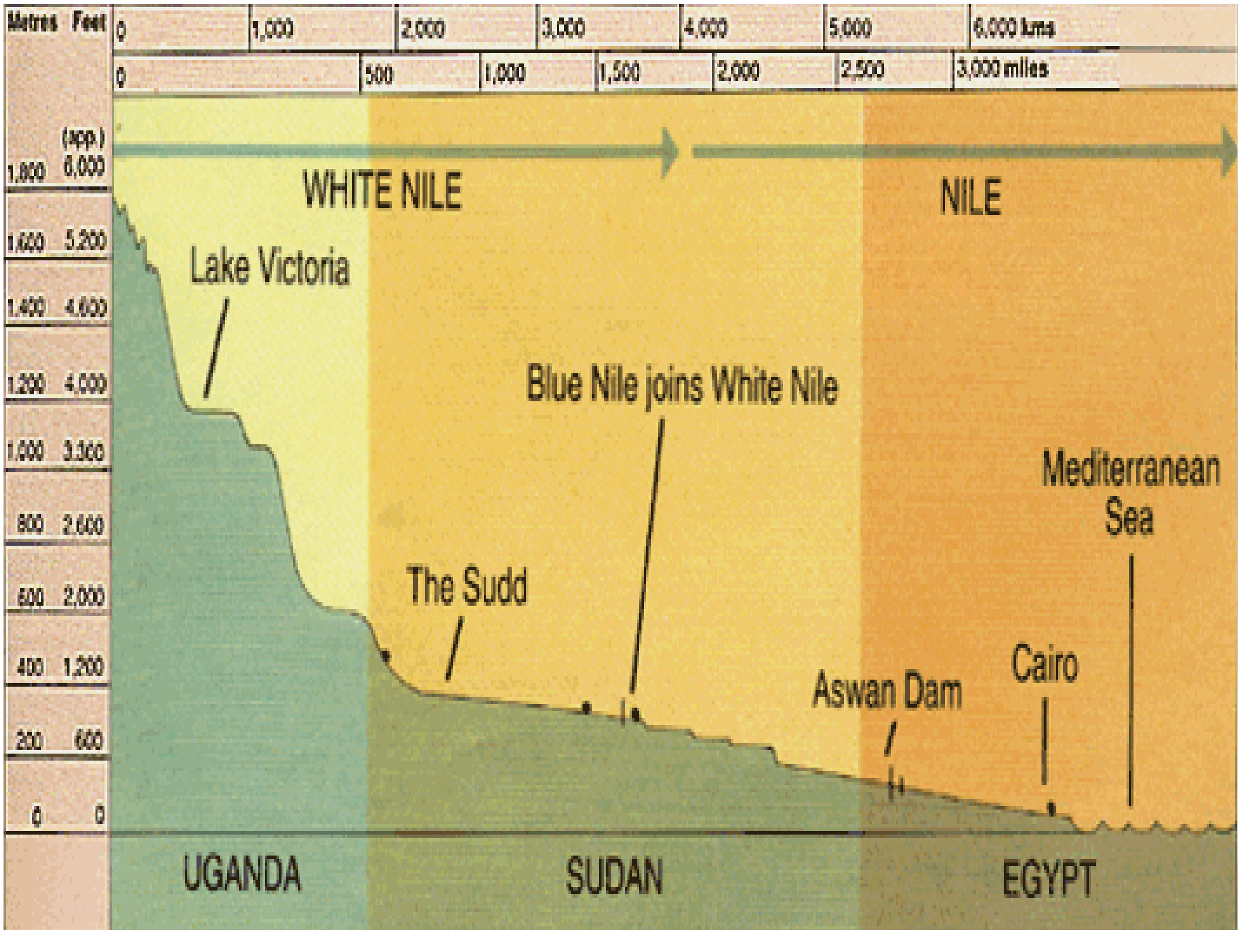


Figure 2: The Blue Nile Joins the White Nile in Khartoum

2. Khartoum City

The major Sudanese and Egyptian cities located along the River Nile system are, from upstream to downstream: Juba, Damazin, Wad Madani, Khartoum, Aswan, Luxor, Cairo, and Alexandria (Figure 3, and Table 1).

City	Location	Longitude	Population	Annual drinking water demand (m^3 /city)
Juba	04°50'N	31°35'E	1,118,233	16×10^6
Damazine	11°46'N	34°21'E	Unspecified	Unspecified
Wad Madani	14° 24′N	33° 31′E	345,000	5133
Khartoum	15°31'N	32°35'E	8,000,000	119×10^6
Aswan	24° 5' 15" N	32° 53' 56" E	275,000	4092
Luxor	25° 41' N	32° 39'E	376,022	5×10^6
Cairo	30°01'N	31°14'E	17,609,800	262×10^6
Alexandria	31°13'N	29°58'E	3,745,000	55×10^6

The city Khartoum is chosen for this study not only because it is the capital of Sudan but because it is also located at the confluence of the main two rivers, the Blue and White Nile, which joined together to form the River Nile in Khartoum (Figure 2).

The confluence of the White Nile and Blue Nile is at 370 meters above sea level (Collins, 1988). It is situated between latitudes 15°26' and 15°45'N and longitudes 32°25' and 32°40'E at the city of Khartoum. The terrain in the region is generally flat or gently sloping, interrupted only 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.

Figure 3: Major cities located along the Nile River.

3. Population

The population density in the populated regions of the Sudan was 14.6 people/km^2 in 1955 and 22.7 in 1970 but declined to 14.8 in 1980 rising slightly to 16.0 in 1988 (Ali et al, 1977). This declining trend is indicative of the large areas progressively occupied, legally as a result of planning, replanting and resettlement programs, and illegally 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 in the 1993 census. Omdurman, west of the River Nile in Khartoum, is the most populated 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 lives within 300 kilometers of Khartoum. In 1990 the population of the three towns that comprise the Khartoum metropolitan area (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, are not unrealistic. According to 2008 census there are about 8 million people living in the city Khartoum, or 20% of Sudan's current total population of around 39.5 million people.

The annual population growth rate in Sudan is about 2%; due to this growth rate the population of Sudan is expected to reach 73 million by year 2035

4. The cost of drinking water in Urban Khartoum.

Most people living in informal settlements in Khartoum suffer from severe economic stress and poverty caused by low levels of education, lack of skills, lack of job opportunities and lack of access to basic services. Research carried out by the Khartoum State Water Corporation (KSWC) showed that households rate access to potable water as the top priority for improvement of living conditions, followed by access to employment, education, health facilities, environmental sanitation, settlement upgrading and security of land tenure (KSWC, 2008).

Figure 4: Typical donkey- drawn water tank used by water vender (KSWC, 2008)

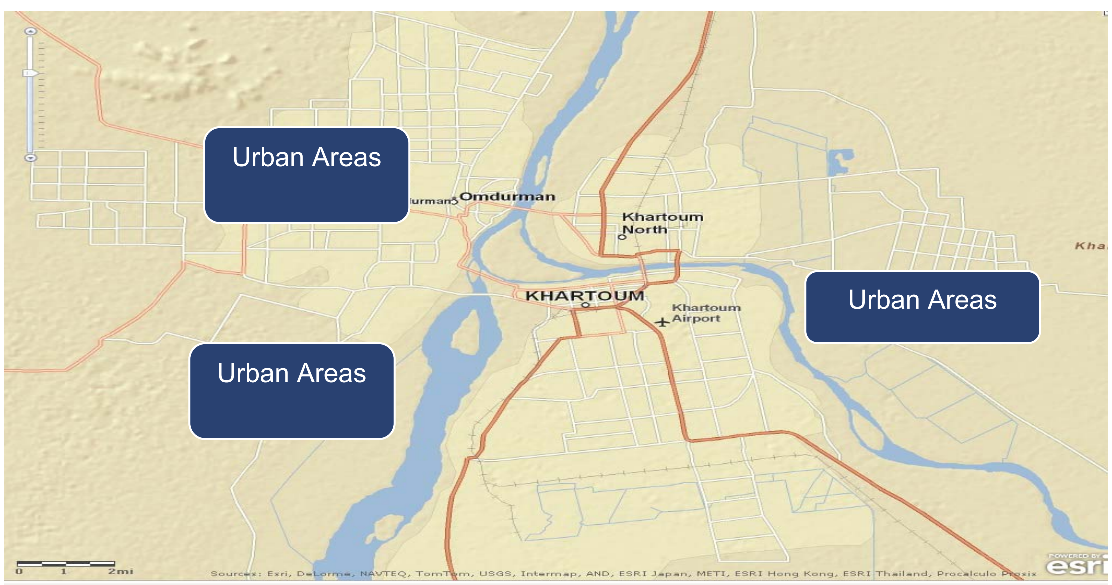


Figure 5: Urban areas in Khartoum city (rectangles represent the urban areas, 15 km from centre of Khartoum).

The monthly expenditure on water in the informal settlements of SP 36.5 (USD 14.6) was found to be 9.2% of the total household monthly income in these informal settlements, an average of SP 393 (USD157 per month). During water shortages due to breakdown of facilities, water prices can increase by 150% while household consumption drastically decreases to 54% of the normal consumption (KSWC, 2008).

Figure 4 below shows how people in urban areas in Khartoum (Figure 5 shows the location of the urban areas) depend on a donkey-drawn water tank to buy untreated water. This is because of the shortage of drinking water treatment plants and a water distribution system that bypasses the informal settlements. Most of the urban areas are too far away from the source of the water (River Nile), at least 15 km, to obtain water personally. So the only practical way to have water inside their homes is to buy the water from the donkey-drawn water tank (Figure 4)

Literature review (Simple technology methods for water treatment)

Simple and appropriate technologies for water treatment are important and required in developing countries due to the shortages of water treatment plants in these countries. Three of these simple methods were discussed in the following paragraphs:

(i) Cloth Filter:

Developed for use in Bangladesh and India, the cloth filter is simple and inexpensive appropriate technology method for reducing the contamination of drinking water (Moss J, 2003). Water collected in this way has a greatly reduced pathogen count. Although it will not necessarily be perfectly safe, it is an important improvement for poor people with limited options.

An old sari, or other suitable cloth, is folded to make four or eight layers. The folded cloth is placed over a wide mouthed container used to collect surface water. It is usually sufficient to rinse the cloth and dry it in the sun for a couple of hours. In any case, lab studies confirmed that with four layers of old sari, 99% of the bacteria was removed (Moss J, 2003)

The preferred cloth used is cotton sari cloth. There are different types of cloth can be used with some effect, though the effectiveness will vary significantly. Used cloth is more effective than new cloth, as the repeated washing fills the space between the fibers (Islam et al, 2003).

(ii) Slow sand filter for household water treatment (Pratap, 2006)

The slow sand filter is a simple technology for household water treatment. The water passes slowly through the filter sand bed (the velocity is between 0.1 to 0.2 m/h). The filter consists of flat stone, clean fine sand and coarse stone (Figure 6). An improvement occurs to the water quality when treated by the filter, especially the removal of bacteria and other microorganisms. The organisms become attached to the sand particles at the

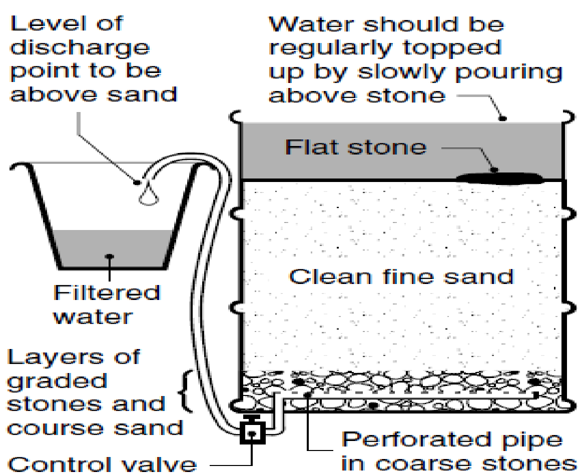


Figure 6: Slow sand filter (Pratap, 2006)

surface and form an active biological layer (known as the schmutzdecke) that traps additional pathogens. These filters also reduce the water turbidity by up to 90%. After a period of use the filter will be blocked and that will affect the water flow rate. Due to this, 15 to 20 mm of the bed sand must be carefully manually removed.

(iii) Household sand filter (Watkins, 2009)

This is a simple and inexpensive technology used to filter household water. This treatment was developed by Watkins in 2009. The water passes through the sand filter to reduce the turbidity. The filter is fabricated using a common, inexpensive, 2 L plastic bottle with sand and gravel layers inside the bottle. A piece of mesh screen is used to fix the sand and gravel layers inside the plastic bottle. This kind of sand filter has shown success in reducing the water turbidity (more details about Watkins (2009) are included in the Methods section).

In this project we will follow Watkins' (2009) method for household water treatment but with some modifications. The experiment will examine different design-related conditions (gravel, sand, etc) to find those conditions that provide the lowest turbidity readings to reach the first objective.

Materials and Methods

In this section we will describe in detail the work plan and steps for each objective.

(1) Objective 1 – Assessment of point-of-use water filtration/ Solar Disinfection System (SODIS treatment:

Study design:

There are at least 2 million people living in urban areas in Khartoum state (Khartoum state includes, Khartoum city, Khartoum north, and Omdurman) using untreated water, and it is important to find inexpensive ways to improve the water quality in these areas. From this point of view it is proposed to use the following procedure, taken from Watkins (see the literature review), for low cost household water treatment, (Watkins, 2009). The main steps for this method are:

1. Removal of water turbidity (Emerick, 1997 as referenced in Watkins).
2. Aeration pre-treatment
3. Inactivation of microorganisms using Solar water Disinfection (SODIS). This application of solar heat and ultraviolet light has been developed by the Swiss Federal Agency for Environmental Science and Technology (SODIS, 2009 as referenced in Watkins).

Method Details:

(i) Data Collection

To evaluate the efficiency of this method for water treatment, it is proposed to apply this method on water samples from surface water sources in Cache Valley, Utah, USA (such as the Logan River), measure the initial water characteristics (turbidity, alkalinity, pH, etc) and the final water characteristics after treatment. In order to evaluate this process and to confirm the results, several samples were collected from the Logan River and Spring Creek in Utah.

Experimental Design:

The design variables in this study are (more details about the design of the experiment are provided in Table 4 and 5):

- The thickness of the materials in each layer of the filter.
- Number of times the filtration process is repeated for the same water sample; and
- The water turbidity measurements before filtration

The response variable is the water turbidity after filtration. Table 2 below shows the required materials for this method (sand filter materials)

Table 2: The sand filter materials

Items Description	Quantity
Plastic bottle	One 2-L
Plastic beverage bottle or similar	One container or collection
Well graded sand	Approximately 2 Kg
Gravel	Approximately 500g
Mesh screen (1mm x 1mm)	One piece

Table 3: The particles and layer sizes for the sand filter are:

Description	Nominal Diameter
Sand	1.25 mm
Fine Gravel	12.5 mm
Coarse Gravel	25 mm

The sand and gravel materials were obtained from the soil mechanics lab at Utah State University; the sizes of the materials were also measured inside the lab by using sieve analysis method. Not all the sizes are same; there is a variety in the material sizes. Actually it is better to use different sizes for the homogeneous purposes between the materials inside the filter. These smaller sizes of gravel and sand are easily fixed inside the 2 liter plastic bottle.

The treatment system was adapted from Watkins, 2009) and is illustrated below:

(i) Assembly (reproduced from Watkins, 2009)

Assembly instruction	**Illustration**
(1) Use a 2-L plastic beverage bottle *Alternative: Any container of similar dimensions (~10 cm in diameter, ~25 cm tall) may be used*	
(2) Cut off the bottom of the bottle *Only remove the very bottom - do not take away too much material*	
(3) Attach the inverted bottle to a sturdy structure *This may be a fence, chair, bench, etc.* *Leave enough room to place the collecting container underneath the filter*	

(4) Add a piece of mesh screen to the bottom of the filter, over the opening *This need not be wire; any material with fairly small openings will be sufficient to prevent the gravel from falling through the opening*	
(5) Add gravel to the bottom of the filter *About 5 cm (2 inches) of gravel should be added*	 
(6) Add about 12-15 cm (5-6 inches) of well-graded sand (varying particle size) *Do NOT use poorly-graded sand (uniform particle size) for the filter media*	 Well-graded sand
(7) The assembled unit should look similar to this	

(ii) How it works (Watkins, 2009)

On the first pass through the filter, the water entrains some of the sand. The first effluent is highly turbid because it contains a mix between the initial turbidity and some dust particles from the sand filter. This effluent needs time to settle these particles (usually 1 hour) and then the water is disinfected using sun light at heat and a source for ultraviolet radiation. As more water passes through the filter, the effluent for the remaining untreated water becomes cleaner with low turbidity. That is because the turbidity-causing particles in the raw water are removed with the sand and gravel in the filter and produce clean water.

“It is important that filtration occurs prior to settling in order to increase the quality of the supernatant. By passing through the filter media, the finer particles in the source water are forced down by the larger, denser particles in the sand. If filtering does not occur first, the finer particles in the source water will take an impractical amount of time to settle” (Watkins, 2009)

(iii) Treatment process

The following process should result in clear, microbial pathogen-free water that is safe for drinking. In this method, turbidity is reduced by a combination of filtering and settling. Small particles in the source water pass through the filter with the small fines contained in the filter media. The particles in the source water are then forced to settle by the relatively larger, denser sand fines. The supernatant that is left once the particles have sufficiently settled should be clear enough to be effectively treated with the SODIS method, provided sufficient temperatures have been achieved for enough time.

1. Removal of turbidity

Pour untreated water through the filter media and collect in a container
Allow this collected effluent to settle - this may take up to 1 day
Once settling has sufficiently occurred, pour the clear supernatant into the clear PET plastic or glass bottle, or clear plastic bag and leave it open to the atmosphere.

2. Aeration pre-treatment:

Agitate/swirl the bottle for several minutes in contact with the air.

3. Removal of microbial organisms using SODIS

Seal the bottle and place in the sunlight for 6 hours. This part of the process can be optimized by placing the bottle on a dark surface or by painting one side of the bottle black. Make sure to point the clear side of the bottle toward the sun to maximize infrared and ultraviolet radiation, and leave some air in the bottle for liquid expansion.

The experiment was done in the Utah State University environmental laboratory. The Hydrolab (Hach, Denver, Co) field water quality sonde, and a (Hach, 2100A, Ames, Iowa) laboratory turbidity meter were used to measure the initial and final turbidity. The effects and interactions of the depths of sand and grave, the initial turbidity, and the number of passes of the water through the filter were examined in a blocked factorial experimental design, with the water source and initial turbidity as the blocking factors.

(2) Objective 2 – Assessment of raw water characteristics:

Study Design:

Because the Nile River is the only source of water in Khartoum state, it is important to analyze the water characteristics, and compare these characteristics with WHO standards (WHO, 2009) for drinking water (Sudan is currently following the WHO for water regulations as a standard for water treatment).

Detailed method

(i) Data collection

The water characteristics data for the River Nile were obtained from Biwater PTY LTD Company (Biwater, 2004). This company worked in Sudan in the period between 2004 till 2009 to construct the biggest water treatment plant in Khartoum. They collected samples during the period from August 2004 to August 2005 for the purpose of design of the Almanara water treatment plant. The water quality at the plant intake is essentially the same as that drawn by private water suppliers to the urban areas in Khartoum.

The main issue to reach this objective is to analyze data for the water characteristics as follows:

1. Calculate the frequency distribution and the maximum, minimum and the average of the turbidity during the four seasons of the year [spring, summer, fall and winter], from August 2004 till August 2005 and compare these values with WHO regulations.
2. Compare other water characteristics for the River Nile with WHO regulations

(3) Objective 3 – Economic Analysis of interim water treatment for unserved areas of Khartoum:

Study design:

As mentioned above, cost is the main obstacle to the provision of safe drinking water in urban areas in Khartoum state. Due to this, water-borne diseases are common in these areas, so if the treatment cost is reduced and people use treated instead of untreated water, many of these diseases will better controlled, with consequent improvement to human health and reduction of the resources allocated to preventable medical treatment.

Detailed Method

The methods for this objective are:

(1) Estimate the overall cost of the water treatment process described in the first objective.
(2) Estimate the cost of the hospital care and medical treatment in Khartoum state due to disease from untreated drinking water.
(3) Compare this cost with cost of the untreated water which consumed by people now in the urban areas that lack public infrastructure.

Data for this objective were provided by:

(1) Federal Ministry of Health in Sudan (FMOH, 2011).
(2) WHO records in Sudan (WHO, 2009)

Results and Discussion:

Objective 1:

Table 4 below shows the experimental conditions and the final turbidity as a result of the experiment (the simple method) for the first objective after the experiment was finshed. The experiment was carried out under the following conditions:

Table 4: The experiment conditions and results with initial turbidity 2650 NTU

Run	Gravel depth (cm)	Sand depth (cm)	Number passes through filter	Initial Turbidity (NTU)	Final Turbidity (NTU)
Block 1 – Logan River					
1	3	8	2	2650	68
2	5	8	2	2650	70
3	3	12	2	2650	75
4	5	12	2	2650	40
5	3	8	4	2650	18
6	5	8	4	2650	12
7	3	12	4	2650	11
8	5	12	4	2650	10
Block 2 – Spring Creek					
9	3	8	2	2100	36
10	5	8	2	2100	33
11	3	12	2	2100	12
12	5	12	2	2100	15
13	3	8	4	2100	21
14	5	8	4	2100	12
15	3	12	4	2100	8
16	5	12	4	2100	8

As shown in Table 4 the experiment was run 16 times with different conditions. The final turbidity ranged between 75 NTU and 8 NTU. These results depend on the variables like the number of filtration passes and the thickness of the gravel and sand.

The data were analyzed by linear regression to estimate the main effects and two-factor interactions of the independent variables on the final turbidity using the statistical software, R. The results are in Table B (Appendix B), below. The results from Table B and from the Q-Q plot (Appendix B) show that the significant variables are: the initial turbidity, the number of filtration passes and the interaction between passes with initial turbidity. These variables have a direct effect on the turbidity removal processes. The other variables and interactions are not significant against final turbidity.

In Table 4 Runs 1, 2 and 3, the range of the final turbidity was found to be between 75 to 68 NTU, which is inadequate for human consumption. Improvement was found in Runs 4 - 6 because the turbidity was found to be between 60 to 40 NTU which is a good indicator for more improvement due to more trials. In Runs 7 and 8 the turbidity was found to be 11 and 10 NTU respectively.

In Table 4 Runs 15 and 16, the turbidity decreased from 2100 NTU to just 8 NTU (99.62% removal), so the experiment succeeded in reducing the turbidity to a reasonable range compared with WHO requirements for turbidity of 2 NTU. Moreover the color and odor of the water with 8 NTU were observed to be similar to high quality treated water. This means people in urban areas in Khartoum will find improvement in drinking water from two sides, quality and color (that is, there would be no significant difference between water treated by the sand filter and water from the treated public water supply).

In Table 4, Runs 15 and 16, the lowest final turbidity was found to be 8 NTU, under conditions of:

Sand filter layer consists of 3 – 5 cm of gravel with 12 cm sand; and four pass filtration to reach 8 NTU turbidity. In this case the initial turbidity was 2100 NTU, which is very high compared with the average of normal turbidity in the Nile River (approximately 300 NTU for the most of the year). Though not tested in this experiment, it is expected that quality of the treated water will be similar if used with lower raw water turbidity.

In fact, however, the main issue with the Nile River water characteristics is the turbidity which is correlated with pathogens. The data collected from Biwater Company for other characteristics (pH, dissolved solids, etc) are in compliance with WHO standards (Table 5). This confirms that, the disinfection by using sunlight combined with sand filtration will improve the household water characteristics in Khartoum urban areas.

Table 5: Nile River water characteristics and WHO standards (obtained from Biwater, 2005)

Parameter	Nile River		WHO standards
	Max	Min	Max or range
pH	8.7	7.9	7.5-8.7
Turbidity (NTU)	6800	45	2
Dissolved solids (mg/l)	120	60	1000
Temp (Celsius)	35	19	N/A
Conductivity $\mu mhos/cm$	24	15	N/A
Calcium as Ca (mg/l)	30	18	17.1
Magnesium as (mg/l)	4.8	2.6	4.8
Nitrate as N (mg/l)	2.4	Nil	3
Sulphate as SO4 (mg/l)	16	6	16

Objective 2 (Data Analysis)

To reach the second objective of this project, statistical data analyses were applied on the Nile raw water data at Khartoum. Appendix A shows a sample of the raw water characteristics (Biwater, 2005). As a result of these data analyses, the normal plot, Tukey's HSD graph, and a frequency histogram were produced as shown in Appendix B, C and D respectively.The following paragraphs discuss more details about these data analysis and graphs.

Appendix B shows the raw water charactaristics for the Nile River as mentioned above, using data collected from Biwater Company during August 2004 till August 2005 (Biwater, 2005) . It is important to study the water quality patterns in the River Nile for purposes of design, cost estimation, decision making, and to evaluate the suitable kind of treatment. In addition, knowing the Nile River turbidity changes during the year by applying statistical analysis on the raw data will be helpful for effective use of the filter system to the people who are using it.

A Tukey's HSD (Berthouex and Brown, 2002), plot in appendix C was constructed to study the difference between turbidity averages during the year, and the results show that only difference between averages occur in July, August and September (yearly Nile flood) compared with the rest of the year. That leads us to think about these months in a different way for treatment like settling the water in sedimentation tanks before treatment by the sand filter.

The above statistical analysis for the water characteristics is important, not just to evaluate the experiments and the efficiency of the sand filter, but will also be important for future improvement at the large scale (constructing a water treatment plants, pipe lines, etc).

In Appendix D, freqency histograms were drawn for the turbidity in each month. A histogram is a graphical representation showing the data distrubution. The histogram displays the raw water turbidity during each month to understand if the sand filter is suitable for the water treatment or we need to find other methods for treatment.

From Appendix D, the River Nile turbidity for August 2004 was found to be 8000 NTU (8000 NTU is the most common reading during August). This turbidity is very high and it's the highest turbidity for the water within all the year because of the Nile flood. The Nile flood occurs between June and September due to sediment transport from the Nile sources (Ethiopia and Uganda) to Khartoum. But there is a possiblity of errors or uncertainty in these readings during the turbidity measurment process in August, because usually turbidity is measured after the suspended solids settle, so 8000 NTU may measured before the settlement of the suspended solids. In September the turbidity started to reduce from 8,000 NTU to just 1000 NTU (the last month for the Nile flood). In the other months from October till May the turbidity readings are in the range from 300 to 80 NTU, a more reasonable range. Another jump in water turbidity occured in June and July, 2005 to reach 500 NTU and 15,000 NTU respectively. But from an engineering point of view this high turbidity can be treated by constructing underground sedimentation tanks at each household (inexpensive clay tanks) for pre - sedimentation to remove the suspended solids during the Nile flood. That may increase the filter efficiency.

Objective 3:

One of the important factors facing the use of the sand filter is the cost. If people in the urban areas of Khartoum found the cost of the sand filter is reasonable, they will be willing to pay for it after explaining its benifts. The judgement is the ability to pay for the filter and the ratio between the filter cost and the total monthly income.

It is important also to estimate the available medical treatment costs in Khartoum and compare these costs with the cost of the water treatment to evaluate the benefits from using treated water during short and long term. Another important factor is the number of victims from using poor quality drinking water inside the houshold (is the medical care for one person or more).

In what follows the cost for the sand filter in Khartoum will examined . All the cost information data come from Biwater's bill of quantities table for Almanara water treatment plant in Khartoum, and from personal information and experience with the Sudanese market (8 years experience as a civil engineer in Sudan).

(i) Sand Filter Cost in Khartoum (Sudan)

A cubic meter cost of sand in Khartoum is SP 10 (10 sudanese pound equal 3.5 dollars, the official rate is $1=2.85). The quantity of sand required is [0.314m^2 (Area) x 0.12m (depth)]=0.038 cubic meter for the total volume of sand needed inside the filter, so the cost of 0.038 cubic of sand is [0.038*3.5] = $ 0.133

The cost of the cubic meter of gravel in Khartoum is SP 15 (US$ 5.75) . The quantity of gravel required is [0.314 m^2 (Area)* 0.05m (depth)]=0.016 cubic meter for the total volume of gravel needed inside the filter, so The cost of 0.016 cubic meter of gravel is [0.016x5.75] =$ 0.092 = $0.10

The 2 l plastic beverarge bottle = SP 1.42 ($0.50)

The mesh piece = SP 1.42 ($0.50)

The total cost of the sand filter =[0.133+0.10+0.5+0.5]= $1.233 say US$1.5, equal to about 4.3 Sudanese pounds.

It is important to understand that this sand filter can work efficiently for at least 2 weeks as tested in the experiment. That means the total cost for filter materials will reach just $ 3 per month for a house. This cost is inexpensive compared with the monthly income for the house hold in urban aresa ($157 per month for house hold according to KSWC), so water treatment will cost just 3% of the total income. In addition, people in these areas may often be able to find the sand and gravel in the streets or yards; it is available even in the center of Khartoum. Moreover plastic bottles are likely to be available in urban areas or in the solid waste stream. Thus the cost will likely range from essentially zero to the monthly US$ 6 as a mximum cost if unseen factors were assumed.

(ii) Medical treatment cost:

In Sudan there are two types of hospitals and clinical centers:

The private sector : medical treatment in the private sector is expensive: a physical check-up without any teatment cost between US$70 to 95 according to Ministry of Federal Health of Sudan 2011.(FMH, 2011)The public sector: medical treatment in public hospitals is less expensive than private and is available in informal areas in Khartoum . The cost of a physical checkup ranges between 5 to 7 US$ (FMH, 2011)The common medication to treat the diseases caused by untreated water is for the antibiotics and the least expensive types cost between US$ 7 to 10.As a result,   the primary cost for medical treatment is ranged between US$ 12 to 17 per capita each time an infection takes place.

Most people in these unserved areas work individually as labourers and the average daily income is about US$10. That means if any work days are missed because of illness, that will lead to a reduction in income during this period and in general people need at least three days rest and recover from any kind of illness. US$ 30 is added to the total cost of medical treatment due to lost wages, so the estimated medical cost is approximately US$ 45 per capita for each infection.

From this analysis a substantial benefit of using the filters for water treatment instead of using untreated water to avoid medical expenses is very clear. However the cost calculations are not as simple as sand filter or medical cost determination. Many other factors can play a vital role in cost calculations. One of these factors is how many days the household need for rest to recover (1 day, 2 days, etc.). Another important factor is usually that children are infected more easily than adults, so the medical expenses may be for more than one person in the household if there is an infant in the house or if children stay home from school. So the actual number of the sick people to determine the medical costs is unkown and will vary from household to household.

If improved drinking water is adopted, the Sudanese government can save part of the health budget by reducing the number of hospitals in the target area. In addition, money paid for medications can be saved and invested in education or infrastructure.

During the period of one decade (10 years), provision of treated drinking water in urban areas in Khartoum will provide large economic benefits. Figure 7 shows a simple comparison between the sand filter cost and medical treatment within just one decade

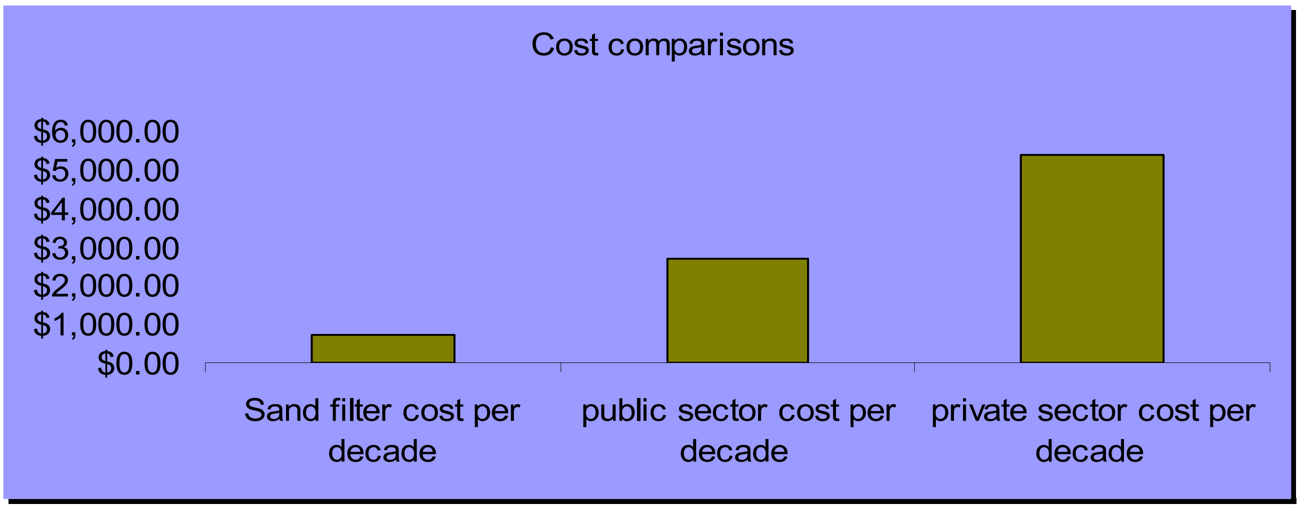
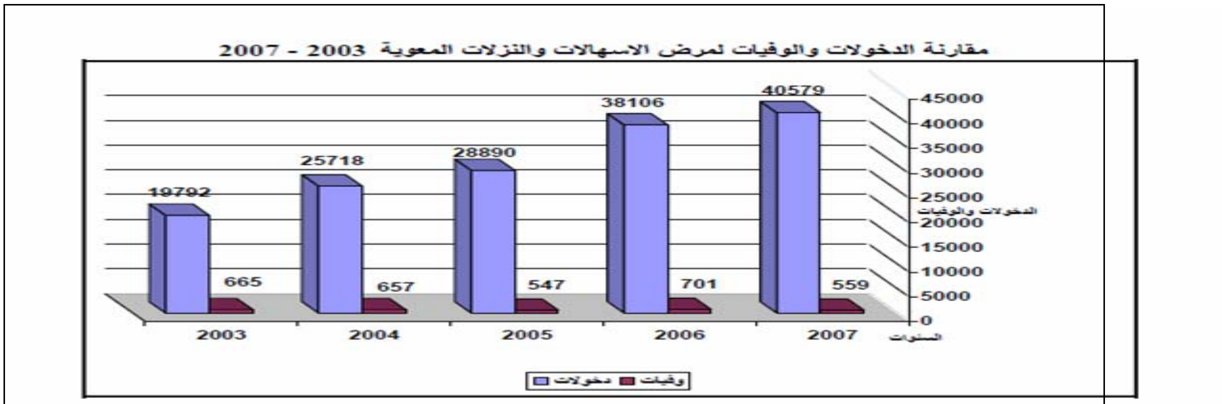


Figure 7: comparison between the sand filter and medical treatment costs during one decade (based on the cost of medical treatment for 3 infected people in each household twice a year)

In order to confirm the importance of treated water and its effects on human health, Figures 8 and 9 show the percentage of deaths compare to illness in the public hospitals in Khartoum due to diarrhea and typhoid during the period from 2003 through

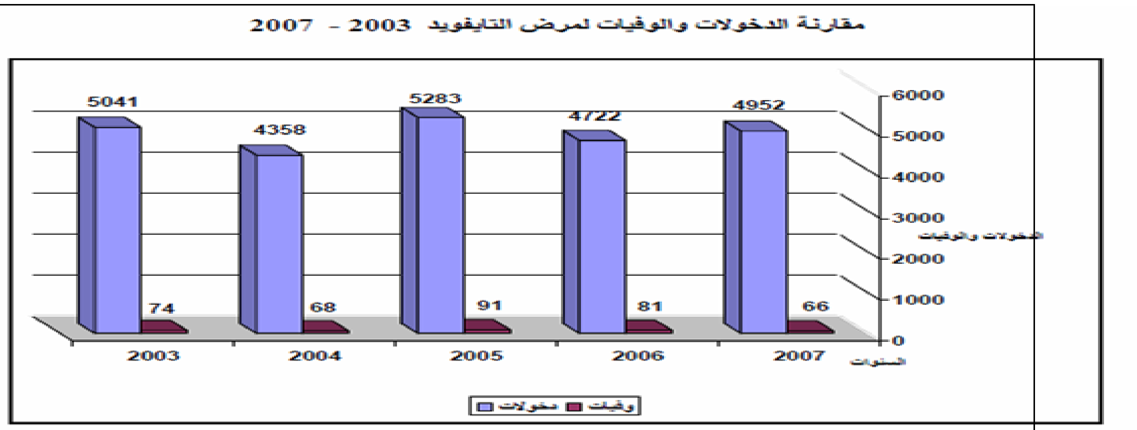
2007 (Federal Ministry of Health in Sudan). The graph shows that in 2007 the total number of cases of diarrhea-type water-borne illnesses is 40,579 with 559 total deaths, while for about typhoid the numbers are 4,952 cases and 66 deaths respectively. Most of the victoms are from urban areas (poor people generally go to public hospitals).

Equally alarming is that the number of sick people in Khartoum from diarrhea has increased, from 19,792 in 2003 to 40,597(diarrhea) in 2007 and for typhoid it is the same rate of increase between 2003 and 2007. These common diseases in urban areas are due to polluted water and the problem will increase if we do not solve it immediately by teaching people how to use these kind of filters for drinking water. Statistical studies show that every year around 250,000 people (Ministry of Federal Populations in Sudan) left their towns in South of Sudan and in Darfur and settle in urban areas in Khartoum.



(translated figure title: Total number of sick and death 2003-2007(diarrhea))

Figure 8: Total number of sick and death in Khartoum due to diarrhea (blue colomns represent the number of illliness and the red represent the number of death) due to diarrhea between 2003-2007 (FMH, 2011).



(translated figure title: Total number of sick and death 2003-2007(typhoid))

Figure 9: Total number of sick and death in Khartoum due to typhoid (blue colomns represent the number of illnesses and the red represent the number of deaths) due to typhoid between 2003 till 2007 (FMH, 2011).

Conclusion:

A simple, appropriate and inexpensive technology for household drinking water treatment was tested to reduce the turbidity and to improve the water quality in the urban areas in Khartoum (Sudan). The experiments consisted of 16 runs with two different initial turbidities, and were used to discover the minimum turbidity and to verify the best filter combinations. The results show that the sand filter succeeded in reducing the turbidity from 2100 NTU to just 8 NTU (> 99% removal) under optimum conditions of 12 cm sand, 5 cm gravel and four passes filtration. It is an important improvement for poor people with limited options.

Khartoum raw water quality (Appendix A) shows that the turbidity is the main issue compared to the WHO regulations (Table 5), and turbidity is correlated with pathogens. Sand filter followed by solar energy for disinfection purposes should improve the household water quality in urban areas in Khartoum un-served by the treatment public water supply because of the high temperature during most of the year in Khartoum.

Statistical analysis was applied to the raw water; the turbidity histogram for each month from August 2004 till July 2005 (appendix B) showed that common turbidity readings during the Nile flood (July till September) are between 1000 NTU and 1500 NTU (appendix B). The turbidity for the rest of the year was found to be lower, around 100-300 NTU. That means the sand filter is capable of reducing the Nile River water turbidity for most of the year to acceptable levels. During the floods when turbidity is high it may better to settle the water in underground tanks or clay tanks before treatment by the sand filter.

Tukey's HSD method was applied to the raw water data to study the difference between averages (Appendix C). The difference was found between July, August and September (the Nile flood period) and the reminder of the year. That is confirming the results from the monthly histograms and leads us to think about other solutions to treat the water during this period to reduce the high turbidity. But there is a possibility of an overestimate of turbidity during this period (the turbidity is not including the suspended solids).

The overall cost of the sand filter was determined; the estimated cost is $6 per month but most of time we can say the cost is nil due to the availability of the raw materials (sand, gravel and plastic bottle) on the streets of Khartoum urban areas.

The medical treatment was determined in both public and private sectors in Khartoum, public sectors costs around $45 per capita and private is more than $100 and most of the people entered hospitals because the diseases from untreated drinking water as shown in Figure 8 and 9 . That is confirming the benefits of using the simple technology method to improve drinking water in these areas from both, the health and economical sides. Medical treatment expenses are at least three to four times the sand filter cost. The cost estimates presented here are uncertain because of the many factors that play a role. However, the differences between the costs of disease prevention vs. treatment are stark.

In one word, the water is essential for improvement and development. Immediate action is required from Sudan’s government and international organizations to help and protect people in Khartoum urban areas from water–borne diseases.

Engineering significance:

In this report, an appropriate and simple method for household water treatment (Watkins, 2009) was tested and improved. Variables like sand, gravel, filtration passes, and initial turbidity were tested and assessed. These variables had significant effects over the final water turbidity.

The other significant factor is the simplicity of the sand filter. Usually people in these lower income urban areas not served by potable water supplies are not well educated but are likely very resourceful. It is important for them to use a simple method for water treatment, so they can build the filter easily by themselves. The shortage of water treatment plants in Khartoum and in other areas in Sudan needs more effort and study. Decision makers and researchers can use the water quality data for the Nile River and the statistical analysis from this report to put together an urgent plan to solve the problem. At least a plan to construct water pipelines to supply the water for these urban areas instead of using donkey-drawn water tanks can make a significant difference.

Decision makers and the government officers can review the physical (economical) benefits from using treated water instead of untreated water. The incidence of diseases from untreated water can be reduced and the budget for medical expenses can be lessened. This money can be invested to construct the infrastructure of Sudanese regions.

Recommendations for further development

The simple method for household water treatment needs further development. Civil and environmental engineers in Sudan have the responsibility to improve the sand filter until it reaches the WHO standards for turbidity. In this report the lowest turbidity reading was 8 NTU; more development is required till it reach at least 2 NTU turbidity. That is mean more work is required. The engineers can do other trials by focusing on the gravel layer inside the sand filter more than the other variables because turbidity was found in this work to be more sensitive to gravel than other factors.

Shortage in the River Nile water data is the main issue against any development. More data about the water quality is essential for further development. In this report we use a data for just 1 year (August 2004 till August 2005) obtained from Biwater LTD Company; no data about water quality in the River Nile are available from government sources. Moreover, no data are available about the *E*. *coli* bacteria, total suspended solids, and dissolved oxygen.

Statistical data about the actual populations in the urban areas in Khartoum are also important for future plans. In fact no updated data about the current populations are available. So it is difficult to determine the actual water consumption.

Despite the shortage of water treatment plants, and the poor water quality, just constructing a water pipeline to carry the water from the Nile River till urban areas in Khartoum (the distance is around 10 miles) can a make a significant improvement.

Reflections:

Before I started my work I was thinking: are my people drinking suitable water? Since I was studying Environmental Engineering 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 water is suitable or not? Or shall I do something to solve this problem?

What is the main reason for the problem? Why still about 25% of people in the Khartoum and other regions in Sudan suffer from a simple thing, which is drinking water and related diseases? Why must residents pay at least 10% from their income to have water without any kind of treatment?

What are the main parameters should I analyze to help find solutions for this problem? Is it the cost, the Nile River water quality, the lack of experience and budget?

Even though the individual filter is not the ideal long-term solution, it can help and make it clear that public investment in drinking water infrastructure will pay off over the long term.

References

World Health Organization. Internet: www.who.int. [May 25, 2010].

Khartoum State Water Corporation (KSWC). Internet: Kswc.gov.sd. [May 26, 2010].

United Nations Children's. Internet: www.unicef.org .[May 31, 2010].

Nabile AlKhodary "The Nile River: Challenges to sustainable development", Nile Basin Society, Canada, 2003.

Robert O Collins: "hydropolitics and the Jonglei Canal"in the waters of the nile, 1 st ed., London. Oxford Studies in affrican affairs, 1990, p. 293-308.

Henry F. Lamb, C. Richard Bates, Paul V. Coombes, Michael H. Marchal, Mohamed Umer. "Late Pleistocene desiccation of Lake Tana, source of the Blue Nile", Quarterly Science Review, Vol. 26, pp. 287-299.

Food and the agricultural foundation of the united nation (FAO). Internet: www.fao.org. [November, 2010]

Ali, S. (1999) Greater Khartoum: The Horizontal Expansion and its Impact on the Development of Settlement (in Arabic)

Jill Moss (2003) "The cloth filter fights cholera". Internet: www.manythings.org, February, 13, 2005 [August, 21, 2011]

Singh Vinay Pratap (2006)" A performance evaluation and modification of the UNICEF upward-flow water filter". International journal of appropriate technologies for water supply and sanitation. Vol 12, pp. 29-31(3).

Colwell RR, Huq A, Islam MS "Reduction of cholera in Bangladeshi villages by simple filtration. The Proceedings of the National Academy of Sciences USA, 2003. Vol 100, pp. 1051-1055.

Chris Watkins, "Design of a low- cost household water treatment system". Internet: www.appropedia.org/Design_of_a_low-cost_household_water_treatment_system, February 2011 [August, 28, 2011].

R.W. Emerick. "Shallow intermittent sand filtration: Microorganisms removal". Small Flows Journal Vol(3)1, pp.12-22

Stuart Seath, John Jennings “Khartoum Raw Water Data”. Biwater PTY LTD. August 2005[May2010].

Paul Mac Berthouex. Linfield C Brown. Statistics for Environmental Engineering. Boca Raton, FL. LEWIS PUBLISHERS. 2002, 170-172.

Swiss Federal Agent for environmental and technology. Internet: www.sodis.ch, July 26, 2011 [August 25, 2011].

Federal Ministry of Health in Sudan. Internet: www.Fmoh.gov.sd. [January, 2011].

Appendices

Appendix A: Sample of Khartoum Raw Water Data

Aug-04		Sep-04		Oct-04		Nov-04		Dec-04	
Date	Turbidity NTU	Date	Turbidity NTU	Date	Turbidity NTU	Date	Turbidity NTU	Date	Turbidity NTU
8/1	12000	9/1	4100	10/1	630	11/1	300	12/1	78.6
8/2	9540	9/2	3620	10/2	624	11/2	276	12/2	76.5
8/3	9330	9/3	3200	10/3	614	11/3	282	12/3	-
8/4	8498	9/4	3700	10/4	627	11/4	253	12/4	76.5
8/5	12900	9/5	3630	10/5	590	11/5	177	12/5	78.7
8/6	11700	9/6	3330	10/6	587	11/6	161	12/6	73.5
8/7	8012	9/7	3170	10/7	556	11/7	186	12/7	78.5
8/8	8130	9/8	2830	10/8	501	11/8	163	12/8	75.2
8/9	10350	9/9	2840	10/9	444	11/9	145	12/9	750
8/10	10500	9/10	1503	10/10	470	11/10	150	12/10	-
8/11	10226	9/11	1130	10/11	450	11/11	141	12/11	69.2
8/12	8610	9/12	1178	10/12	449	11/12	-	12/12	69.1
8/13	8600	9/13	1018	10/13	405	11/13	-	12/13	71.2
8/14	10721	9/14	917	10/14	390	11/14	90	12/14	69.8
8/15	7650	9/15	893	10/15	390	11/15	-	12/15	69.6
8/16	6957	9/16	784	10/16	373	11/16	89	12/16	70.8
8/17	5196	9/17	830	10/17	409	11/17	81.6	12/17	-

Appendix B Analysis of Filter Improvement Experiments

Table B. Significance of Main Effects and Interactions for Turbidity Removal Experiments

Factor	Estimate	Std. Error	*t* value	Pr(>|*t*|)
Gravel	-3.062	2.355	-1.300	0.25023
Sand	-5.687	2.355	-2.415	0.06051.
Passes	-15.563	2.355	-6.607	0.00119**
Turb.Init	9.938	2.355	4.219	0.00833**
Gravel:Sand	-1.063	2.355	-0.451	0.67081
Gravel:Passes	1.062	2.355	0.451	0.67081
Gravel:Turb.Init	-1.937	2.355	-0.823	0.44818
Sand:Passes	2.437	2.355	1.035	0.34816
Sand:Turb.Init	1.688	2.355	0.716	0.50577
Passes:Turb.Init	-9.688	2.355	-4.113	0.00924**
**** Significant at 0.001-0.01 probability**				

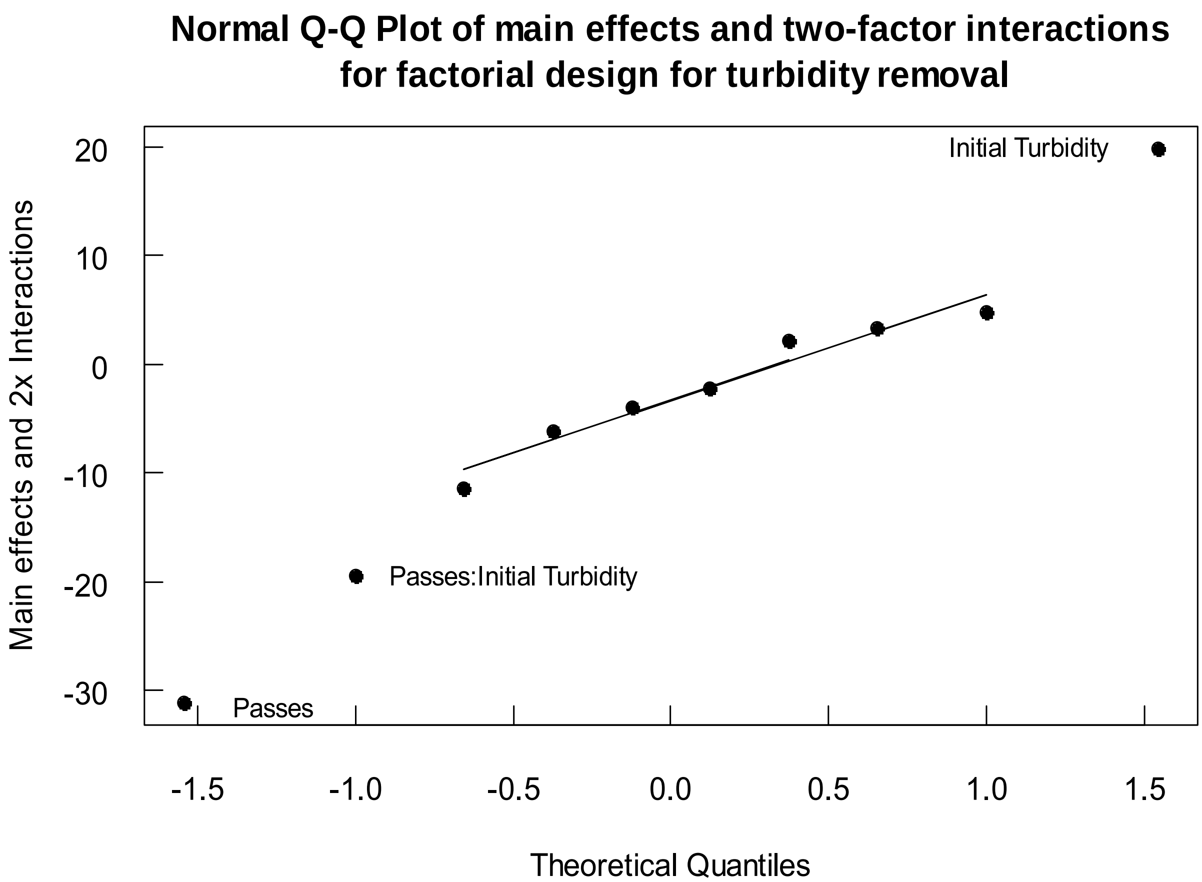


Figure 10: Normal plot for experiments 1 and 2, combined

Appendix C: Tukey graph

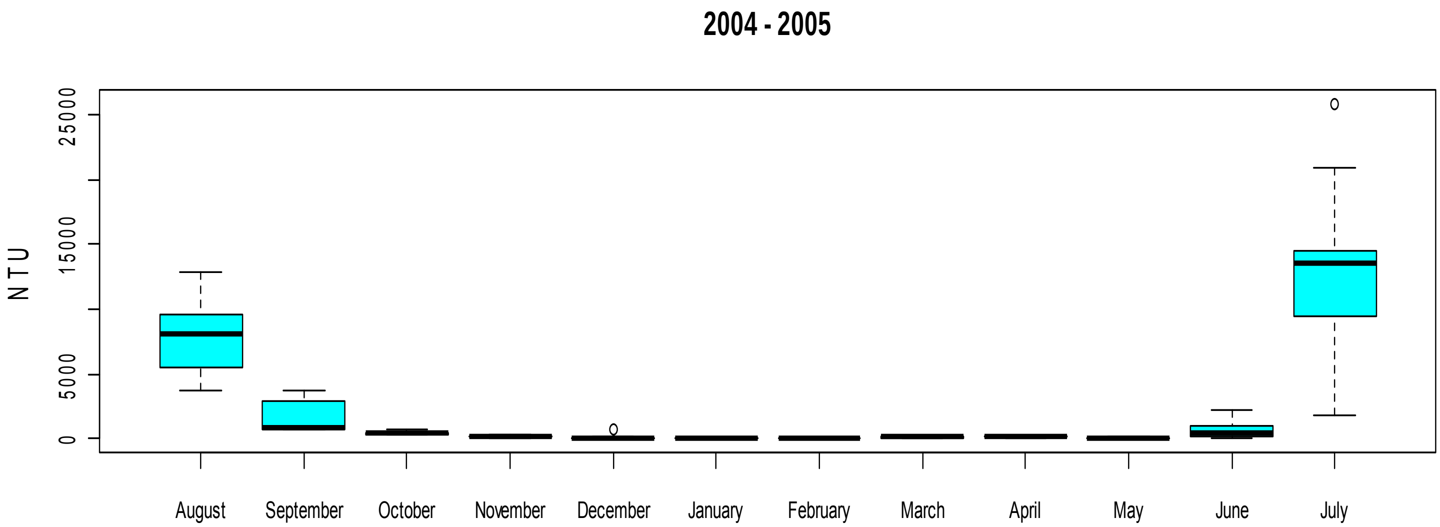
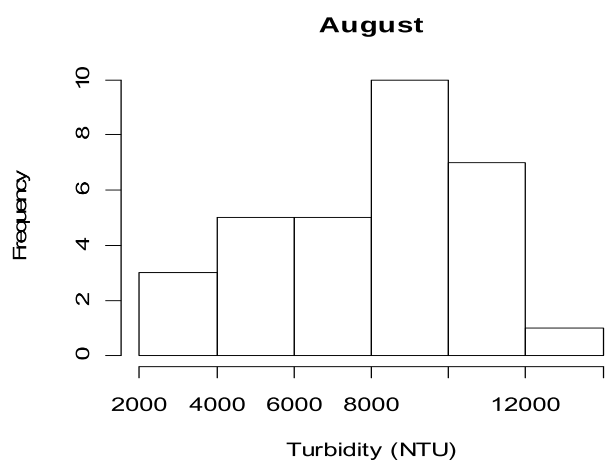
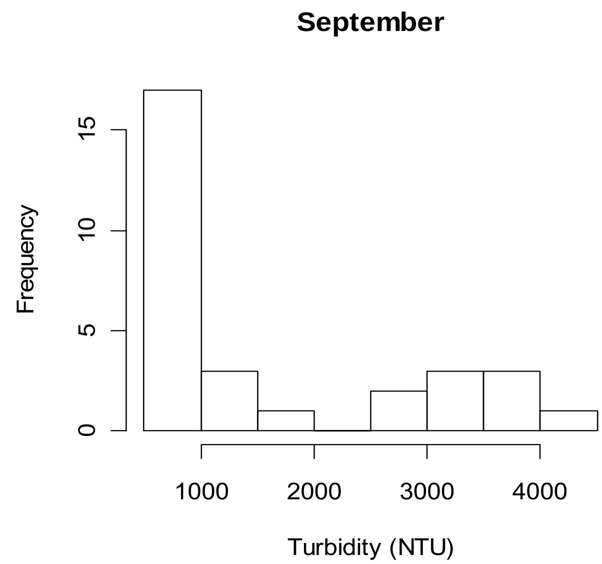
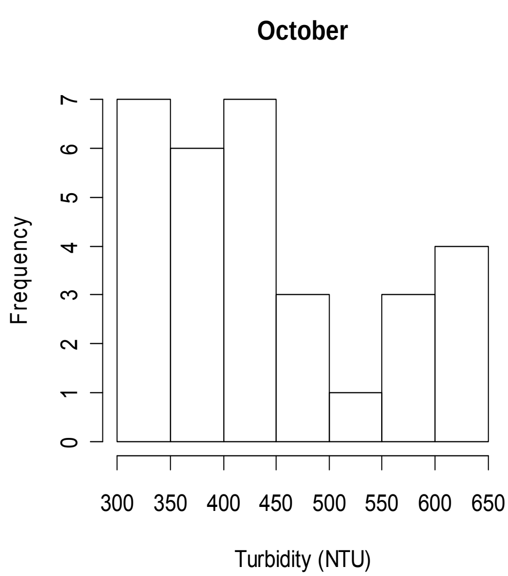


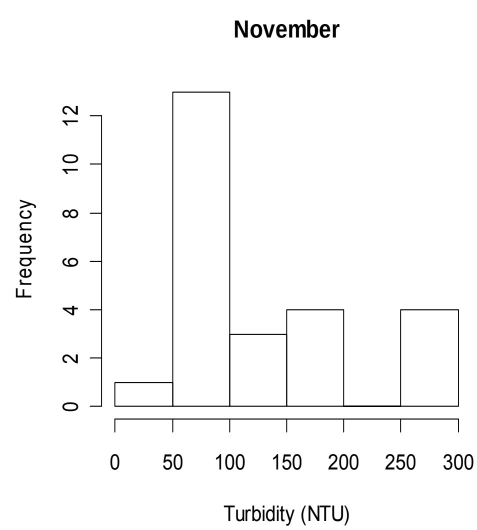
Figure 11: Comparison between monthly average turbidity between 2004- 2005 (Tucky's HSD graph)

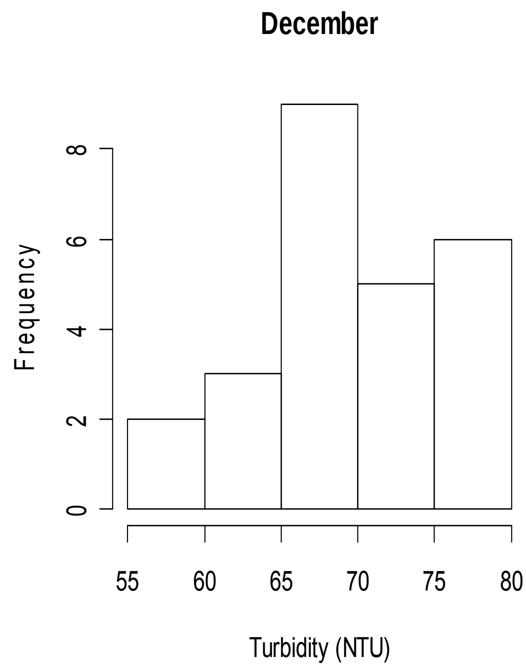
Appendix D: Frequency Histograms for Nile River Turbidity from August 2004 till July 2005

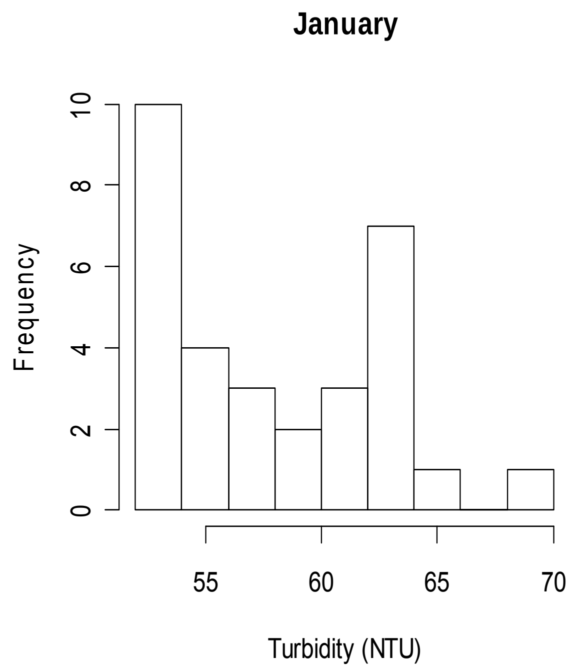


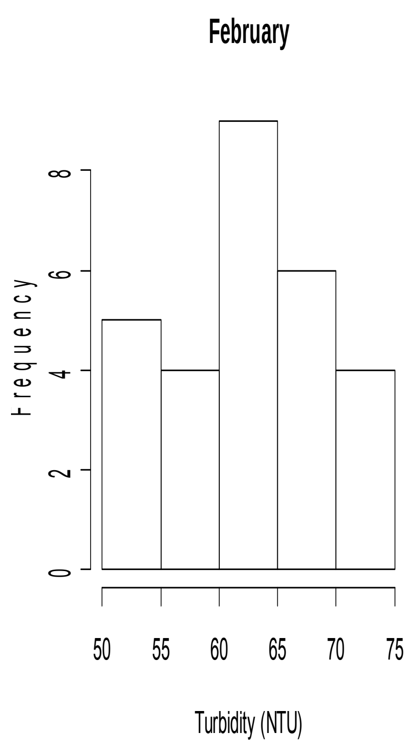


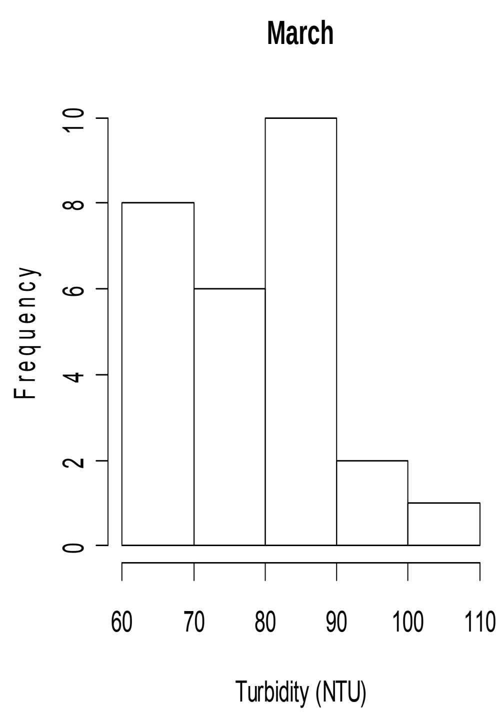


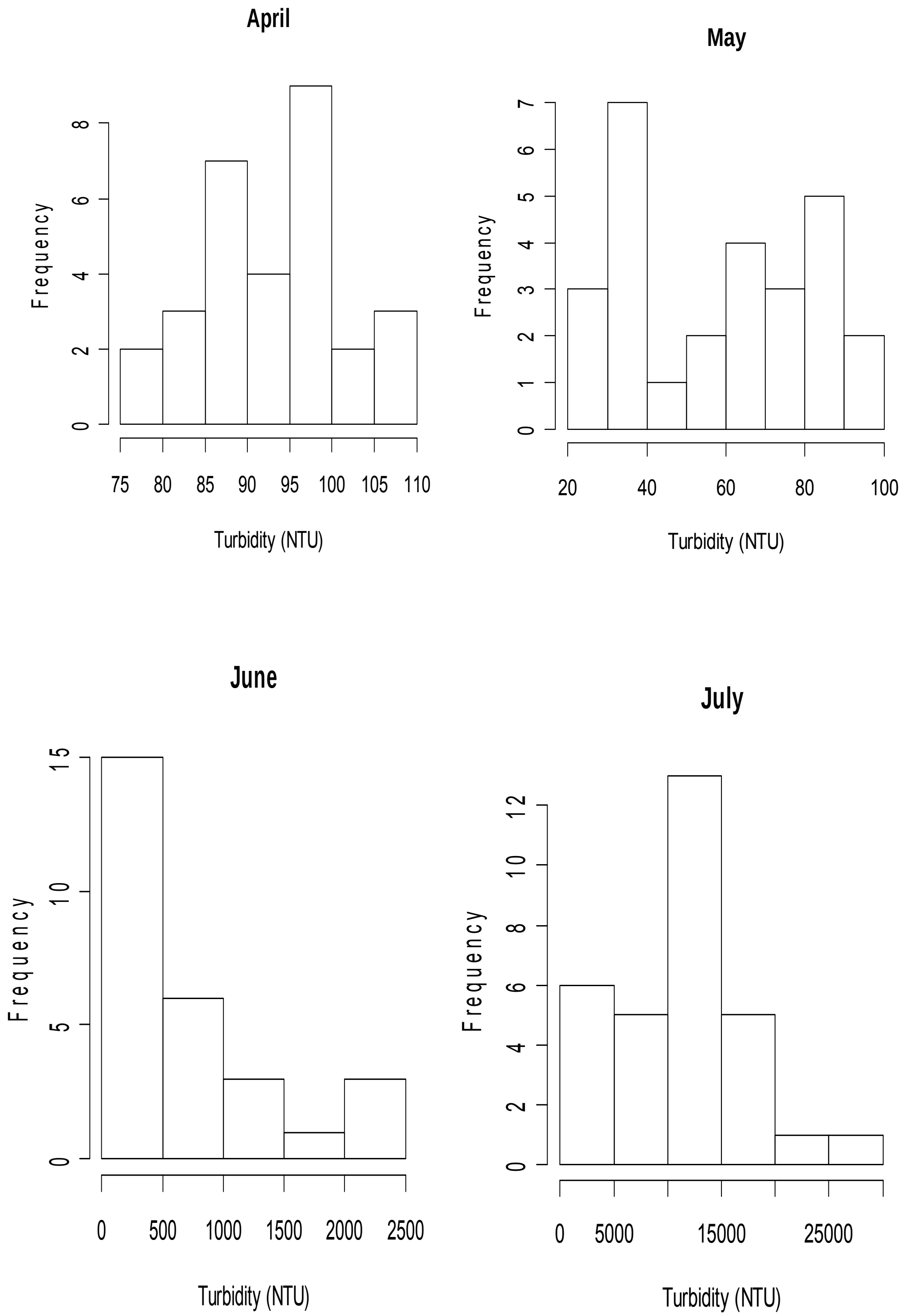



December
Frequency
0
2
4
6
8
55
60
65
70
75
80
Turbidity (NTU)


January
Frequency
0
2
4
6
8
10
55
60
65
70
Turbidity (NTU)


February
Frequency
0
2
4
6
8
50
55
60
65
70
75
Turbidity (NTU)


March
Frequency
0
2
4
6
8
10
60
70
80
90
100
110
Turbidity (NTU)


April
Frequency
0
2
4
6
8
75
80
85
90
95
100
105
110
Turbidity (NTU)
May
Frequency
0
1
2
3
4
5
6
7
20
40
60
80
100
Turbidity (NTU)
June
Frequency
0
5
10
15
0
500
1000
1500
2000
2500
Turbidity (NTU)
July
Frequency
0
2
4
6
8
10
12
0
5000
15000
25000
Turbidity (NTU)