Assessment of Drinking Water Quality for Human, Animal and Food Processing in Khartoum

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DEDICATION

To the memory of my father

To my beloved mother

To my elder sister Siham

With love and respect

Samia

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My deepest sincere and gratitude are due to my supervisor Dr. Suliman Mohamed ElHssan for his help, advice, constructive criticism, guidance help and encouragement throughout all the stages of this work.

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Abstract

This study was done to investigate the drinking water quality intended for human, animal consumption and food processing. Twenty two water sources from Khartoum and Khartoum North area were selected (Eleven from each area) as follows: Six samples source from well water of different food processing plants (bottled water ,milling , food , dairy and milk factory) and five different locations of tap water of main distribution system (mixed animal farm , public and private hospitals and residential house.

A total of sixty six samples were collected three from each sample sources to estimate the mean value of each parameters examined.

Samples were subjected to microbiological physical, and chemical examinations and analyzed to investigate the level of health hazards in each sample .

All water samples collected were transferred to Al Morgan Central Laboratory for water safety for examination of Microbial, Physical and Chemical contaminants, Soil Science Dept. Laboratory (Faculty of Agriculture, University of Khartoum for analysis of trace minerals contaminants and Laboratory of Institutes of Environmental Studies, University of Khartoum for the analysis of heavy metals.

Results obtained were compared with international and national drinking water guidelines in attempt to evaluate the quality of drinking water in Khartoum State.

This study revealed that raw well water of some location in Khartoum and Khartoum North was polluted by total coliform and total count bacteria and the analysis results does not cope with international (WHO,1993) and national Sudanese Standard Methodology Organization (SSMO, 2002) and Khartoum Water Corporation (KWC, 2002) standards. After treatment pollution incidence in raw well water samples decreased, however, slight pollution occur in some water samples after treatment.

From the physical and chemical analysis this study showed that the raw well water samples examined for turbidity, sodium , chloride exceeds the permissible level of WHO (1993) and Sudanese Standard Meteorology Organization (2002) standards. Concentration of heavy metals such as fluoride , nitrate , sulfate and water alkalinity does not agree with the national and international standards of WHO and SSMO. After treatment for raw well water, anions and cations concentrations cope with national and international standards of drinking water which proved treatment of water intended for drinking and food processing is important.

Most of the tap water samples collected and examined from the main distribution sources are suitable for human and animal consumption and food processing.

A set of recommendations were suggested to improve drinking water quality standards.

بسم الله الرحمن الرحيم

خـــلاصـــة الاطـــروحـــة

تمت هذه الدراسة بغرض اختبار جودة مياه الشرب للاستهلاك الأدمى و الحيوانى والتصنيع الغذائى بمنطقتى الخرطوم والخرطوم بحرى. لقد تم اخذ العينات من عدد 22 مصدر مياهـ ، احدى عشر لكل منطقة ستة منهم مياه أبار لمصانع أغذية (مصانع مياه شرب معبأة ، مطاحن دقيق ، مصانع أغذية ، مصانع البان ومصانع منتجات البان) وخمسة مواقع لمناطق تغـذى بالشبكـة الرئيسـية مثل مـزارع حيـوان مختلطـة، مستشفيات عامـة وخاصـة ، منازل بكل من منطقتى الخرطـوم والخرطـوم بحـرى.

لقد تـم أخـذ سـته وسـتون عينة ثلاثـة من كـل مصدر تم اختياره وذلك لتقييم وتحديـد المتـوسـط الحسـابى لكـل عنصر تـم اختـباره .

تم تحليل واختبار الخصائص الميكروبيلوجية والفـيزيائية والكيميائـيـة بغرض تحديد و معرفة صلاحية المياهـ للشرب والتصنيع الغذائى والأثـر الصحـى على الانسـان والحـيوان.

تم اختبـار العينـات المختاره بكل من معمل محطـة مياهـ المقـرن ومعمـل قسـم علـوم التربة بكلية الزراعـة ومعمـل معهـد الدراسـات البيئيـة بجامعـة الخرطـوم للعناصر الثقيلـة.

تمت مقـارنة النتائج بالخصائص العالمية والمحليـة لتقـييـم جـودة مياهـ الشـرب بالسـودان ووجدت الدراسة أن معظم العينات المختارة تعتبر صـالحة للاستهلاك الأدمـى والحيوانى والتصنيع الغذائى عدا مناطق قليلة.

لقـد وجـدت الدراسـة ان مياهـ بعـض الأبـار بمنطقـة الخـرطـوم والخرطـوم بحـرى قبـل المعالجـة ملـوثة ببكتـريا كوليفـورم البقـايـا الأدميـة والحيوانـية وبكتريـا الكوليفورم الكليـة، ووجد ان نتائج الاختبارات لاتتفق مع الخصائص العالمية والمحليـة لهيئة الصحـة العالمية 1993 وهيـئـة المواصفـات السـودانية وهيئـة مياهـ الخرطـوم 2002 .

بعـد معالجـة المياهـ قلـت نـسبة التلـوث فـى المياهـ تحـت الاختبـار. ولكـن ظهـرت نـسبة للتلـوث البكتيرى لمياهـ بعض الأبـار بعـد دخولهـا لخطوط المعالجـة.

وجدت الدراسة أيضا أن نسبة العكر وتركيز الصوديوم والكلوريد لمياه بعض الأبار لا تتفق مع الخصائص العالمية لهيئة الصحة العالمية 1993 وهيئة المواصفات والمقاييس السودانية 2002 . كما وجدت الدراسة أن نسبة تركيز العناصر الأخرى مثل العناصر الثقيلة الذائبة مثل الفلورايد والنترات الذائبة والسلفات وقلوية المياه لا تتفق مع الخصائص العالمية والمحلية لمياه الشرب.

وبعد عمليات المعالجة لبعض مياه الأبار أصبحت نسب تركيز بعض العناصر الكيميائية الملوثة للماء تتفق تقريبا مع الخصائص العالمية لجودة المياه مما يؤكد أهمية المعالجة لمياه الشرب والتصنيع الغذائى.

لقد وجدت الدراسة أن معظم العينات المختارة من الشبكة العامة تعتبر صالحة للاستهلاك الأدمى والحيوانى والتصنيع الغذائى عدا مناطق قليلة.

لقد تم رفع عدد من التوصيات من شأنها ان تحسن جودة المياه بالسودان.

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Chapter One

1. Introduction

Water is a fundamental part of our lives. It has been ranked by the experts as second only to oxygen as essential for life. Water has importance inside cells and externally because it has interesting chemical and physical properties; it can be found naturally in all three of its states. It is the most abundant component in any organism, the lowest is 20% in seeds, while jellyfish are 99% hence the transparency. The average adult body is 55 to 75% water ⅔ of our body weight is water. A human embryo is more than 80% water. A newborn baby is 74% water. Everyday our body must replace 2½ quarts of water to stay healthy, lots of fresh water has been needed (Rona, 1995). Water plays vital roles in the metabolism of all cells and in photosynthesis (providing raw materials) in plant cells. It is also used on a much larger scale for transport. Blood is mostly water, and is used to transport food, hormones, waste products (ammonia and urea) and oxygen. Aside from aiding in digestion and absorption of food, water regulates body temperature and blood circulation, carries nutrients and oxygen to cells (Kleiner, 1999).

Conversely, lack of water (dehydration) can be the cause of many illnesses and sicknesses. Batmanghelidj (1992**)** noted that chronic dehydration may cause certain problems for the body, including

hypertension, asthma, allergies, and migraine headache. In livestock consumption, dairy cows need 4 to 4.5 lbs. per lb. of milk produced and a single cow may consume over 300 lbs. of water daily via drinking water and ration. Drinking water generally provides 80-90% of water needs. Most ground or surface waters are satisfactory for livestock. Some are not, however, resulting in poor performance or even death in animals confined to them (Guyer, 1977).

Guyer (1996) mentioned that water quality is affected by many factors such as salinity, nitrates, sulfates, alkalinity, bacterial contamination and other factors.

In Sudan the incidence of fecal streptococci contamination of water was variable, it is highest during rainy seasons (July-August) and lowest during winter (November - December) in village around Khartoum while, in the city there were no fecal streptococci contamination (Elroufaai, 2000). High coliform contamination portable water was also observed (A/Rahman, 2001).

All people whatever their development and their social and economic status have the right to have access to an adequate supply of safe drinking water (WHO, 1984).

Due to rapidness and significant awareness of people on drinking water quality and health risks associated with contaminated water on human, animal health and the quality of the processed food the general objectives of this study are as follows:

1. To examine the water samples from the selected sources for the presence of microbiological and chemical contaminants.

2. To determine whether water is safe for human and animal consumption and food processing or not.
3. To examine the effect of treatment on raw water.

Chapter Two

2. Literature review

2.1 Water importance for human and animal consumption:

Kleiner (1999) reported that water is a basic nutrient of the human body and is critical to human life. It supports the digestion of food, adsorption, transportation and use of nutrients and the elimination of toxins and wastes from the body. It is necessary for all digestive, absorption, circulatory, and excretory functions, as well as for the utilization of the water-soluble vitamins. It is also needed for the maintenance of proper body temperature. Water must be continuously replaced since on average 250 ml is lost on a daily basis through breathing. Nutritionists have difficulty in suggesting an exact daily requirement because the amount of water required will vary depending on the climate and whether any type of activity is undertaken. By drinking an adequate amount of water each day-at least eight glasses (2 litres), man can ensure that his body has all it needs to maintain good health. Man can live without food for several weeks, but he can go less than a week without water. The best source of water for drinking is plain water. But other beverages, such as fruit juices, milk, and non caffeinated drinks are also good sources of water. Fruits and vegetables can also be good sources of water.

Sauer (1974) advised that "In a moderate climate most of people need around 6-8 glasses of fluid a day; for example, water, milk, fruit juice, tea or coffee, to keep the balance right. However, if one have sweated a lot, because it is hot or been exercising, water requirements increase; a good guide is to have an extra one litre of water for every hour of strenuous exercise.

The World Health Organization (1996) stated that "the 'absolute minimum' quantity of water to sustain hydration remains elusive, as this is dependent on climate, activity level and diet". WHO notes that some hydration needs are met through fluid obtained from food, however they disregard this contribution in their recommendation of daily water requirements, because, on a global basis, "the proportion of fluid obtained from food may vary significantly in response to diet and culture from negligible to all hydration needs". They note that allocating the full hydration component to drinking water alone may over-estimate the quantity of water required, but "this is believed to be no more significant than the variation likely to occur due to activity levels and temperature." The WHO (1984) recommendations for daily requirements of drinking water are given in table (1).

Table 1: Daily requirements on drinking water for human adult female and male.

	Average conditions	Manual Labour in high temperature	Total needs in pregnancy/lactation
Female Adults	2.2 litres	4.5 litres	4.8 litres (pregnancy) 5.5 litres (lactation

Male Adults	2.9 litres	4.5 litres	-

When people do not drink enough water, the signs and symptoms include headaches, poor concentration, tiredness, increased risk of developing, kidney infections, and constipation (Batmanghelidj, 1992).

Kleiner (1996) reported that from energy production to joint lubrication to reproduction, there is no system in the body that does not depend on water. Water is essential for the preparation of foodstuffs and requirements for food preparation included water used for washing of cooking utensils, and water used for cooking.

Kleiner (1996) reported that water is the most abundant ingredient of animal body in phases of growth and development. Calf's body contains 75 to 80% water at birth and about 55 to 65% water at maturity. Of all farm animals, lactating dairy cows require the greatest amount of water in proportion to their size because water constitutes 86 to 88% of the milk they yield.

Water constitutes approximately 60-70 percent of an animal's live weight and consuming water is more important than consuming food **(**Faris *et al.*, 1997) and domesticated animals can live about sixty days without food but only about seven days without water. Livestock should be given all the water they can drink because animals that do not drink enough water may suffer stress or dehydration.

It has been reported that an estimate of water intake of cattle should be made based on production factors, which affect water intake. Water consumption requirements depend on factors such as: kind and size of

animal ,rate and composition of gain, pregnancy, lactation, type of diet, level of dry matter intake, level of activity, quality of water, temperature of the water offered and surrounding air temperature (Rodenburg, 1985).

Boyles (1997) reported that limitations of water intake reduces animal performance quicker and more dramatically than any other nutrient deficiency. Cattle can tolerate poor water quality better than humans, but if concentrations of specific compounds found in water are high enough, cattle can be affected. Most factors affecting water quality are not fatal to cattle. Cattle may not show clinical signs of illness, but growth, lactation and reproduction may be affected, causing an economic loss to the producer.

2.2 Microbiological contaminants of drinking water

Bradshaw and Powell (2004) reported that**,** microorganisms include the organisms in water that are capable of reproducing or growing either in water or in the host, once ingested. These contaminants include bacteria, protozoa (often in cyst form), viruses, fungi, and worms. These microbiological contaminants have been responsible for the majority of illness, disease, and death associated with polluted drinking water. Outbreaks still occur, though infrequently, in the United States, but are much more common in less developed countries where less attention is given to sanitation, water protection, and water treatment (Chapelle, 1999). The human illnesses such as typhoid, dysentery, cholera, hepatitis and giardiasis have been linked to drinking water contaminated by human wastes (Mancl, 1989).

The bacterial contamination of water for livestock does not usually cause apparent production problems (Guyer, 1977).

Mancl (1989) reported that adult animals are more tolerant of bacteria than young animals.

Another type of bacteria referred to as iron bacteria does not cause disease, but does form reddish-brown slime that coats the inside of pipes, fouls pumps and clogs waterers (Blagojevich and Whitaker, 1999).

Madsen and Ghiorse (1993) explored the suitability of ground-water habitats for microbial growth, and compared ground-water environments to other aquatic habitats (lakes, rivers, streams, wetlands) they found that microbes are abundant and most sun surface materials contain bacteria which can be cultured. Chapelle (1993) related microbial activities in ground water to subsurface geochemistry. Fyfe (1996) has recently proposed that the term "biosphere" be extended to include deep subterranean habitats, based on recent research base on recent research demonstrating the presence of bacteria in deep subsurface oil and gas deposits and their role in mineral formation.

Norris (1994) provides a general review of the role of bacteria in natural and augmented bioremediation of fuels and solvents in ground water. Most of the activities of bacteria in ground water are the direct result of the outstanding metabolic versatility of bacteria.

Bacterial contamination can result from a number of sources. Human and animal wastes are primary source of bacteria in water. These source of bacterial contamination include runoff from feedlots, pasture, dog runs, and

other land areas where animal wastes are deposited, Additional sources include leakage or discharge from septic tanks and sewage treatment facilities. Bacteria from these sources can enter wells that are either open at the land surface, or do not have water–tight casings or caps, or not have a grout seal in the annular space (the space between the wall of the drilled well and the outside of the well casings). Insects, rodent or animals entering the well are other sources of contamination **(**Sharon *et al*., 2004). Bacterial contamination cannot be detected by sight, smell or taste. The only way to know if a water supply contains bacteria is to have it tested. Frequency of testing depends on the size of the population served **(**Sharett *et al*., 1980**)**.

Mancl (1989) reported that a test for fecal streptococci, must be performed to determine if it is of human or animal origin. The ratio of fecal coliforms to fecal streptococci vary for different animals, if the ratio is near four the waste is from humans and if the ratio is less than one it is from animal wastes.

New York State Department of Health (2005) stated that coliform bacteria are found in the digestive tract of all birds and mammals. Most coliform bacteria are not harmful themselves, but point to an unsanitary condition and possible presence of disease-causing organisms.

The coliform bacteria may not form disease but can be indicator of pathogenic disease (Sharon, 2004).

Skipton *et al*. (2004) recommended that drinking water from private wells should be tested for the presence of bacteria at least once a year or when work has been done to the water supply system or any time there is any change in the water.

The drinking water quality standard for coliform bacteria is set at less than one coliform organism per 100 ml of water.

Bacterial guidelines for livestock water supplies are for adult and young animal 1,000 and 1 fecal coliform/100 ml respectively and for dairy wash water is 1 coliform/100 ml.

In Sudan, Karar (2002) reported that no yeast and moulds were reported in either raw river or treated water, while bacterial pollution of Blue Nile water near Almugran can be attributed to large number of cafeterias and restaurants along Blue Nile and close to Almugran raw water intake point.

2.2.1 Bacteria:

2.2.1.1 Coliform

Total coliforms include bacteria that are found in the soil, in water that has been influenced by surface water, and in human or animal waste. Fecal coliforms are the group of the total coliforms that are considered to be present specifically in the gut and feces of warm-blooded animals. Because the origins of fecal coliforms are more specific than the origins of the more general total coliform group of bacteria, fecal coliforms are considered a more accurate indication of animal or human waste than the total coliforms.

Escherichia coli is the major species in the fecal coliform group. Of the five general groups of bacteria that comprise the total coliforms, only E. coli is generally not found growing and reproducing in the environment. Consequently, *E. coli* is considered to be the species of coliform bacteria

that is the best indicator of fecal pollution and the possible presence of pathogens.

New York State Department of Health (2005) stated that most coliform bacteria do not cause disease. However, some rare strains of *E. coli*, particularly the strain 0157: H7, can cause serious illness. Recent outbreaks of disease caused by *E. coli* 0157: H7 have generated much public concern about this organism. *E. coli* 0157: H7 has been found in cattle, chickens, pigs, and sheep. Most of the reported human cases have been due to eating under cooked hamburger. Cases of *E. coli* 0157: H7 caused by contaminated drinking water supplies are rare.

The most basic test for bacterial contamination of a water supply is the test for total coliform bacteria. Total coliform counts give a general indication of the sanitary condition of a water supply (New York State Department of Health, 2005).

Mancl (1989) reported that testing for bacteria is the only reliable way to know if your water is safe. Water can not be tested by the look, taste, or smell of the water if disease-causing organisms are in it. The New York State Department of Health (2005) recommends that well owners test their water for coli form bacteria at least once a year. If bacteria problem was experienced in the past, it is recommended that the well should be tested frequently.

Several studies have shown that bacteria such as E. Coli are destroyed by the bacteria population in the rumen of cow, therefore though determining the number of bacteria such as *E. coli* in the water supply is

essential for human consumption, it is of little value for animal (Harris, *et al.*, 1992).

2.2.1.2 Legionnaire's Disease

Legionellosis is a form of pneumonia caused by Legionella bacteria. The disease develops following inhalation of the bacteria after it has been vaporized from water either from a shower, a humidifier, or air conditioning system. Legionella bacteria are found naturally in soil and water. Legionella multiplies occasionally in heating and hot-water systems. Legionella bacteria have been found in many public water systems. They are resistant to chlorine disinfection and colonize in some water heaters operated at temperatures of 120 F˚ to 140 F˚ (Bradshaw and Powell, 2004). Outbreaks of the disease have been traced to lodging and institutional water heaters. They undoubtedly infect some home water heaters as well and may be inhaled when taking a shower.

2.2.2 Viruses:

Viruses exist almost everywhere in the environment and produce a variety of diseases and health conditions. Those of most concern in our drinking water are from the intestinal tract of humans and animals (Bradshaw and Powell, 2004). Viruses find their way from sewage into our drinking water supply producing a variety of diseases and health conditions.

Viruses can live several days to months outside of live hosts. Testing for viruses in water is complicated and expensive, and there is a lack of standardized test procedures (Bradshaw and Powell, 2004).

2.2.3. Protozoa

Protozoa are microscopic, usually single-celled microbes which live in water and are relatively large in comparison to other microbes. Protozoa eat bacteria, and many are parasitic (CDC, 1994).

2.2.4. Giardia

Giardi lamblia (commonly referred to as Giardia) are single-celled microbes contained in a group known as protozoa. When ingested, they can cause a gastrointestinal disease called giardiasis. Giardiasis is a frequent cause of diarrhea. Symptoms may include diarrhea, fatigue, and cramps. Waterborne giardiasis may occur as a result of disinfection problems or inadequate filtration procedures (CDC, 2005).

Mancl (1989) reported that there is no routine test a water company can use to check for Giardia contamination. Negative results are not a guarantee of a safe water supply because of the unknown sensitivity of the test. Giardia cysts are more easily identified in stool samples taken from an exposed person or animal. One gram of feces may contain as many as 2 million cysts.

2.2.5 Algae:

Occasionally, heavy algae growth occurs in stagnant or slow flowing bodies of water. Some species of algae, mainly the blue-green algae, can under certain circumstances be toxic to livestock. These single cell or chain-like groups of cells are free floating and green, blue-green or brown in colour. They commonly appear as small specks or "grass clippings" in the water. The blue-green algae are single cell cyanobacteria that produce a microcystin toxin. The algae thrive in warm, stagnant water that is high in nitrogen and phosphorus. The largest release of toxin occurs when the algae dies. Cooler, rainy or windy weather can cause an algae kill. Early symptoms of poisoning are muscle twitches, scouring, photosensitivity and loss of co-ordination. If sufficient quantities of the toxin are consumed,

paralysis and respiratory failure occurs rapidly. Animals are not able to breathe and suffocate to death within minutes. Thus, animals are usually found close to the suspect water source. Removing animals from affected areas is the only sure method of preventing poisoning. Care should be taken to limit the growth of algae in water for livestock consumption (Rodenburg, 1985).

2.2.6 Water related diseases:

The water related diseases are either water borne disease, water washed disease, disease transmitted by water related insects vector or water based diseases (Madsen, 1993). The disease related to water are demonstrated in table (2)

Table (2) The main water related diseases：

Disease	Types of water relation ship
Cholera Infectious hepatitis Typhoid Paratyphoid Amoebic dysentery	Water–borone
Gastroenteritis Bacterial dysentery Ascariasis Conjunctiuritis Diarrhea Leprosy Scabies *Tina Saginata*	Water-washed

Trachoma	
Malaria Onochocerocasis Yellow fever	Water-related Insect-vector
Schistsmiasis Guinea worm	Water based

Source: Madsen (1993)

2.3 Chemical contaminates:

A number of chemical contaminants have been identified in drinking water, The presence of chemical contaminants in drinking water can be attributed to a variety of sources, including the improper disposal of household products and cleaning solvents, leaking land-fills and underground storage tanks, discharge from commercial businesses and industries, and increased pesticide use during the past 50 years (Geldreich,1990).

2.3.1 Salinity:

Water is a very good solvent, and all natural water contain inorganic salts, the calcium, magnesium and sodium chlorides, sulfates, and bicarbonates predominating, these may present in high concentrations that they cause harmful osmotic effects resulting in poor performance, illness or even death (Guyer, 1977).

2.3.1.1. The use of saline water for livestock and poultry.

From the standpoint of total dissolved solids (TDS), water containing less than 1,000 ppm should be excellent for all classes of livestock, while water containing 1,000 to 2,999 ppm of TDS should be satisfactory for all classes of livestock, those water approaching the upper limit may cause some watery droppings in poultry, but they should not adversely affect the health or production of birds. However, water containing 3,000 to 4,999 ppm should be satisfactory for livestock. If not accustomed to it for a few days, but they will adapt to it in time. If sulfate salts are predominant, they may show temporary diarrhea, but this should not harm them. It is, however, a poor to unsatisfactory water for poultry. It may cause watery

feces, and particularly near the upper limit, it may cause increased mortality and decreased growth, especially in turkey poults. Water containing 5,000 to 6,999 ppm TDS can be used for livestock except those that are pregnant or lactating, without seriously affecting their health or productivity. It may have some laxative effects and be refused by the animals until they become accustomed to it. It is unsatisfactory for poultry. However, water containing 7,000 to 10,000 ppm TDS consider as poor livestock water that should not be used for poultry or swine. It can be used for older, low-producing ruminants or horses that are not pregnant or lactating with reasonable safety. Finally water containing over 10,000 ppm TDS is considered unsatisfactory for all classes of livestock (Peterson, 1999).

2.3.2 Hardness

Water hardness is a measure of the cations (cations are ions which bear positive electron charges) dissolved in the water and is therefore, related to dissolved solids. The more cations dissolved in the water the "harder" the water. The most common cations of this type are calcium and magnesium. Iron, strontium, and manganese may also contribute, but they are seldom present in appreciable amounts. Hardness is usually reported as an equivalent amount of calcium carbonate ($CaCO_3$) (Harris *et al*.,1992).

Generally, waters are classified according to degree of hardness that water is less than 75 mg/l $CaCO_3$ is considered as soft water and water that is 75 to 150 mg/l is considered as moderate and water that are 150 to 300 mg/l $CaCo_3$ is considered as hard and water that is greater than 300 mg/l is considered as very hard water (Harris, *et al.,* 1992).

Wilkins *et al*. (1981) reported that healthy water criteria –hardness is 170 g/I and TDS 300 mg/I.

Sharrett *et al.* (1980) stated that hard drinking water generally contributes a small amount toward total calcium and magnesium human dietary needs. They further stated that in some instances, where dissolved calcium and magnesium are very high, water could be a major contributor of calcium and magnesium to the diet. (Bragg and Bragg, 1986) noted that Minerals in drinking water are more easily and better absorbed than minerals from food.

Much research has been done on the relationship between water hardness and cardiovascular disease mortality. Numerous studies suggest a correlation between hard water and lower cardiovascular disease mortality (Herman and Jennings, 1996). Reasearch on heart disease and cancer shows a healthy water is hard water and moderately high in TDS ((Bragg and Bragg, 1986). Experimental evidence shows hard water actually contribute to the prevention of certain types of calculi (Kidney stones or water belly) formation (Guyer, 1977). It was found that animals drinking the hard water have less of the harmful agent in their tissues than the animals drinking the soft water (Epestein and Zavon, 1974).

2.3.3. Alkalinity

The alkalinity of water is defined as its capacity to neutralize acid. Alkali substances in water include hydroxides or bases. They can be detected by their acid taste and by the fact that they cause red litmus paper to turn blue.

Guyer (1977) reported that waters with alkalinities of less than 1,000 ppm are considred satisfactory for all classes of livestock and poultry. Above that concentration they are probably unsatifactory, although for adults they may be of little harm at concentrations less than about 2,500 ppm unless carbonates in excess over bicarbonates.

Rodenburg (1985) reported that water alkalinity is ppm assayed as Ca Co_3 and water of less than 500 ppm alkaline and pH 6.8 to 8 its nature of alkalinity is the presence of bicarbonate is not harmful. Water up to 1,000 ppm, alkaline, pH 7.0 to 8 and its nature of alkalinity is mostly presence of bicarbonate is considered satisfactory for both livestock and poultry. Water above 1,000 ppm alkaline and pH 8.0 to 9.0 and its nature of alkalinity is presence of carbonate is considered unsuitable for livestock particularly young animals. Water less than 2,500 ppm alkaline, pH 10 and its nature of alkalinity is presence of carbonate may do little harm in adult animals, unless carbonates are present in excess of bicarbonates

2.3.4 Nitrate:

Nitrate is a colourless, odourless, and tasteless compound that is present in some groundwater. Nitrate can not be detected unless water is chemically analyzed. Nitrate can be expressed as either NO_3 (nitrate) or

NO_3-N (nitrate-nitrogen). Nitrate levels above the Environmental Protection Agency (EPA) Maximum Contaminant Level of 10mg/1 NO_3-N or 45 mg/1 NO_3 may cause methemoglobinemia in infants (Self and Waskom, 1998).

Report of methemoglobinemia are extremely rare. Clinical infant methemoglobinemia was first recognized in 1945. About 2,000 case were reported in North America and Europe by 1971. Fatality rates were reported to be approximately 7-8 percent. From 1960 to 1972, however only one death from blue baby syndrome was documented (Stanton, 1992).

The poisoning of cattle by nitrates was first observed prior to 1990, and there have been many cases since then. As rule it results from their eating forages of high nitrate content (Follett and Self, 1998).

Proper management of fertilizers, manures, and other nitrogen sources can minimize contamination of drinking water supplies (Self and Soltanpour, 1997).

The maximum contaminant level (MCL) in drinking water as nitrate (NO_3 is 45mg/l, where MCL as NO_3 -N is 10 mg/l (USEPA, 1996)

2.3.4.1 The use of water containing nitrate for livestock and poultry.

Water containing less than 100 ppm nitrate nitrogen, experimental evidence indicates that this water should not harm livestock or poultry. While water containing 100 to 300 ppm is also save unless feed containing relatively high level nitrate is fed especially in case of cattle or sheep during drought years (Self and Waskom, 1995), However, water containing over 300 ppm nitrate nitrogen could cause typical nitrate poisoning in cattle and

sheep and its use for these animals is not recommended. The use of this water for swine , horses and poultry should also be avoided (Guyer,1977).

2.4 Heavy metals and dissolved solids contaminants:

Natural water may contain or become contaminated with certain toxic elements such as arsenic, mercury, strontium, cadmium or radioactive substances. While these may harm animals, the major concern is that they do not accumulate in animal products used for human consumption. Analyses for these elements are only done when there are good reasons to suspect their presence (Rodenburg, 1985).

2.4.1 Asbestos:

People drinking water with asbestos are starting to show that they have higher levels of cancer deaths of the stomach, small intestines, pancreas, gastrointestinal area of lungs. Yet these cancers are starting to show up after only 10 to 15 years of exposure (Donsbach and Walker, 1981).

The U. S Environmoental Protection agency (2001) stated that the public health standard for asbestos in drinking water is 7 million fibre per litre (7 MFL).

2.4.2 Arsenic

Arsenic and cadmium have been shown to have an undesirable toxic effect on humans and animals at low concentrations and are injurious to plant life. Effects on humans are to cause cramps, nausea, vomiting and diarrhea (UWP, 1999).

The U.S Environmental Protection agency (2001) affirmed that the

public health standard for arsenic in drinking water is 10 parts per billion (ppb).

2.4.3 Iron

High concentration of iron as low as 3 ppm will leave reddish-brown stains on white porcelain, enameled ware, fixtures and fabrics. Iron bearing waters tend to stain or impart unpredictable colors and are therefore unsatisfactory for many industrial purposes. Small quantities of iron are essential for plant growth and development, however, toxicity occurs when concentrations exceed 5 ppm (UWP, 1999).

2.4.4. Aluminum

Aluminum is seldom found in significant amounts in our water supplies and is therefore of little importance with regard to most beneficial uses. High concentrations are occasionally detected due to industrial discharges from treatment plants. Recent research indicates that high levels of aluminum may cause Alzheimers disease (McLachlan 1996). The amount of aluminum present in drinking water has been recommended to be below 200 micrograms per liter (WHO, 1996).

2.4.5 Copper

The aesthetic objective for copper in drinking water is therefore ≤1.0 mg/L. This level is below the taste threshold for copper in water, is protective of health, and contributes to minimum nutritional requirements. WHO (1984) reported that the presence of copper in domestic water systems has caused green staining of laundry and plumbing fixtures at concentrations as low as 1.0 mg/L. The U.S. Environmental Protection

Agency (U.S. EPA) has determined that copper levels in drinking water should not exceed 1300 ug/l. Long-term exposure (more than 14 days) to copper in drinking water which is much higher than 1,000 ug/I has been found to cause kidney and liver damage in infants (U.S. EPA, 1990).

2.4.6 Lead

Lead is toxic to people, farm animals and crops in both acute and chronic exposures. It is toxic even at fairly low concentrations (U. S. EPA (1990) has established an enforceable lead concentration action level for public water supplies. The lead action level is 15 micrograms per liter (mg/l).

2.4.7 Silver

Low silver concentrations do not appear to be harmful to people. At higher concentrations, however, it becomes an irritant and a dose of 10 grams can be fatal to people (UWP, 1999).

2.4.8 Chromium

At low concentrations chromium can cause nausea and vomiting. It is also toxic to crops. Different forms of chromium have different degrees of toxicity. Hexavalent chromium is carcinogenic in humans (UWP, 1999), Chromium has the potential to cause the following effects from a lifetime exposure at levels above the MCL: damage to liver, kidney circulatory and nerve tissues; skin irritation.

The MCLG for chromium has been set at 0.1 parts per million (ppm) because EPA believes this level of protection would not cause any of the potential health problems described below.

2.4.9 Mercury

Mercury is unique among metals in that it can evaporate when released to water or soil. Also, microbes can convert inorganic forms of mercury to organic forms which can be accumulated by aquatic life (U. S. EPA, 1999).

Mercury has a tendency to accumulate in the food chain and is highly toxic to animals and people (NRC, 1977).

U. S. E PA (1991) recommended that the drinking Water Standards and the maximum contaminants levels (MCL) of mercury is 2 ppb., therefore, exposure in long or short term to mercury in drinking water at levels above MCL cause kidney damage.

2.4.10 Barium

Most surface water and public water supplies contain less than 0.38 ppb. The soil contains 0.1-0.6 ppb. All of these levels are safe (UWP, 1999).

U. S. EPA (1996) has established a maximum level of 1,100 ppb of barium in drinking water. EPA also has said that an average-sized adult exposed to 1,500 ppb every day for 70 years will not experience adverse health effects.

2.5. Common dissolved solids in water.

2.5.1 Sodium and potassium

All natural waters contain sodium and potassium, but usually only in small amounts in natural or unpolluted surface waters in humid regions. In

arid regions, or areas of limited rainfall, water may contain larger amounts of sodium. Moderate amounts of sodium and potassium have little effect on the usefulness of water, except that potassium is a requirement for plant growth (Robertson *et al*., 1979).

The Environmental Protection Agency (EPA, 1999) doesn't set a mandatory upper limit for sodium in water, but suggests an upper limit of 20 milligrams per liter (quart) to protect individuals on sodium-restricted diets.

In recognition that potassium in drinking water poses no risk to human health, the European Commission has removed the limits it set on the allowable potassium concentration in drinking water from December 2003 (Robertson *et al*., 1979).

2.5.2 Bicarbonates and carbonates

Carbon dioxide dissolves in water to form a weak acid, which greatly increases the ability of water to dissolve minerals. Carbonates are particularly susceptible to solution in water containing carbon dioxide. Carbonates, however, do not occur in normal waters with pH values below 8.4 (UWP, 1999)

2.5.3 Sulfates

Sulfates in high concentrations are undesirable in waters containing high levels of calcium, magnesium or sodium because they create Epsom salts and permanent hardness. At ordinary concentrations, however, sulfates are considered beneficial to irrigation (UWP, 1999).

Sulfate in drinking water currently has a maximum contaminant level (MCL) of 250 milligrams per liter (mg/L), based on aesthetic effects (i.e., taste and odor) (U. S E PA, 1991).

2.5.4Chloride

Chloride is dissolved from most rocks and soils. Waters in humid regions are usually low in chloride content. Arid/Semi-arid regions often contain high levels. (UWP, 1999).

Low to moderate concentrations of both chloride and sulfate ions add palatability to water. In fact, they are desirable for this reason. Excessive concentrations of either, of course, can make water unpleasant to drink. The EPA Secondary Drinking Water Regulations recommend a maximum concentration of 250 mg/1 for chloride ions

2.5.5 Floride

Fluoride is minute in amounts in natural surface water. Ground waters occasionally show undesirably high fluoride concentrations. About 1 ppm of fluoride in water decreases the incidence on dental decay. Water containing fluoride exceeding 1.5 ppm can cause dental defects if consumed during the calcification or formation of teeth (UWP, 1999).

2.5.6 Boron

Boron in drinking water is not a hazard to humans. It is an essential element in the nutrition of higher plants, yet, if present in concentrations exceeding About 1 ppm in water it may be harmful to most orchard crops (UWP, 1999).

2.5.7 Silica

Silica is dissolved from practically all rocks. Silica is a major nutrient source for diatoms, an important link in the biological food chain. However, silica contributes to the formation of boiler scale and water used in the formation of paper must be practically free of silica (UWP, 1999).

2.5.8 Usage water containing dissolved solids for human and animals:

According to WHO standards (WHO standards from Environmental Protection Agency,2002), the water for human and animal use should not contain dissolved contaminants higher than 0.2 mg/l of aluminum, 250 mg/l of chloride, 15 cu color, 1.0 mg/l copper, 2.0 mg/l fluoride, 0.5 mg/l foaming agents, 0.3 mg/l iron, 0.05 mg/l manganese, 0.10 mg/l silver, 250 mg/l sulfate, 500 mg/l TDS, and 5mg/l zinc , the water should has odour not more than 3 threshold odor number and pH between 6.5 to 8.5.

2.6. Drinking water disinfectant:

2.6.1 Chlorine:

The addition of chlorine to our drinking water started in late 1890's and had wide acceptance in the United States by 1920 (Price, 1969) Protozoa and enter viruses are more resistant to chlorination than bacteria (Andelaman, 1985).

Villanueva *et al. (2004)* reported that **e**xposure to disinfection byproducts in drinking water has been associated with an increased risk of bladder cancer. data are from 6 case-control studies of bladder cancer that used trihalomethanes as a marker of disinfection byproducts.

Schwartz (2001) based on his experiments showed the basic cause of

atherosclerosis and heart attacks and most common forms of strokes is chlorine contained in processed water. Geldreich (1990) reported that Chlorine is so dangerous according to that it should be banned. The continued use of chlorine as the main drinking water disinfectant in the United States only adds to organic chemical contamination of drinking water supplies. The current federal standard regulation of trihalomethane do not adequately protect consumers from the multitude of other organic chlorination by-products that have been shown in many studies to be toxic. (Conacher, 1988). Studies from New Orleans, Maryland and Ohio revealed higher levels of Trihalomothanes (THMs) that resulted in higher levels of cancer (Robertson *et al*. ,1979).

Page *et al.* (1976) reported that drinking chlorinated tap water destroys beneficial bacteria in body which will weaken and eventually damage one's immunity, and should be avoided. Disease to show its horrible face.

2.6.2 Ozone:

Ozone is a form of oxygen-an unstable form. Stable oxygen that we breathe in every day is O_2. Ozone is O_3 so there is an extra electron looking to pair itself. This instability is what makes ozone a universal cleanser (Renate and Andrew, 1987).

Ozone is widely used in Europe for purifying drinking water and swimming pools. Ozone is also used to purify bottled waters (Sartori, 1994). Our bodies desperately need more oxygen. Cancer cells, for instance, can only grow in an anaerobic or oxygen–deficient environment (Sartori, 1994).

1.6.3 Iodine:

Iodine kills bacteria and disease causing organisms, but is slow acting. Iodine, however, ineffective as algicide. An iodine residual of 0.5 to 1.0 mg/l should be maintained, and at this level gives the water little or no iodine taste. Iodine is appropriate for occasional use in vacation homes, campgrounds and restaurants (Mancl, 1989). Iodine treatment of drinking water supplies for dairy cattle is also a concern. Because dairy cattle can drink from 15 to 30 gallons of water a day, normal levels of iodine used for disinfection may cause iodine carryover into milk (Bauder and Vogel, 1988).

1.6.4 Fluoridation

Fluoride as inorganic chemical contaminants its sources in drinking water are erosion of natural deposits; discharge from fertilizer, water additive which promotes strong teeth and aluminum factories its maximum contaminate level (MCL) is 4.0 mg/l and its potential health effects from Ingestion of water is bone disease (pain and tenderness of bones), children may get mottled teeth (WHO and EPA, 2002).

Flouridation is a highly emotional and contraversial issue (Brown *et al* ., 1984). Burk (1982) stated that more people have died in the last thirty years from cancer connected with fluoridation than all the military deaths in the entire history of the United States.

2.7. Disinfection of contaminated drinking water:

Water can be purified by a number of means and techniques which include:

2.7.1 Purification

Purifying devices remove everything from the water, harmful bacteria and beneficial minerals (Banik, 1975) reported that, this stripped water cannot sustain life even in a fish bowl. All fish require minerals to prosper, and if allowed to live in these types of water will perish. If this type of water is ingested for long periods of time, it can leach out valuable body minerals such as potassium, magnesium, sodium and calcium. Mineralized water is needed for all cellular functions and if there are no minerals in drinking water your body will rob the minerals from somewhere in the body to satisfy its needs (Bragg and Bragg, 1984).

1.7.2 Distillation

The water is distilled by boiling the water, catches the resulting steam, and condenses the steam on a cold surface (a condenser). Nitrates and other minerals remain behind in boiling tank.

Edward (1996) reported that, cooking foods in distilled water pulls the minerals out of them and lowers their nutrient value. They suggested addition of 3 tablespoons of organic apple cider vinegar per gallon of distilled. This supplies the body with over 90% of the minerals needed on a daily basis.

1.7.3 Reverse osmosis:

Reverse osmosis forces water under pressure throughout a membrane that filters out minerals and nitrate. Once-half to two-thirds of the water remains behind membrane as rejected water (Geldreich, 1990).

1.7.4 Ion-exchange:

Ion-exchange takes other substances, such as chloride, and trades places with nitrate. An ion exchange unit is filled with special resin beads that are charged with chloride. As water passes over the beads, the resin takes up nitrate in exchange for chloride. As more water passes over the resin (Geldreich, 1990).

1.7.5 Boiling

Advantages of boiling water disinfection method are readily available, well-suited volatile organic chemicals out of water will drive volatile organic chemicals out of water and extremely effective disinfectant that will kill even giardia cysts (NRC, 1977). Disadvantages are it requires a great deal of heat and time to bring water to boil and cool before use, can give water stale taste, typically limited capacity, not an in-line treatment system and requires separate storage of treated water (Mancl, 1989).

1.7.6 Ultraviolet light

Advantages of ultraviolet light treatment are as follows: it does not change taste or odor of water, kills bacteria almost immediately, compact and easy to use. Disadvantages are as follows: It require high electrical demand, provide no residual disinfectant, requires pretreatment of cloudy or cloured water, requires cleaning and new Lamp annually (Mancl, 1989).

1.7.7 Chlorination

Advantages of chlorination methods are as follows, provides residual disinfectant, residual easy to measure, chlorine readily available at reasonable cost, low electrical requirement, can be used for multiple water

problems such as (bacteria, iron, manganese and hydrogensulfide) and can treat large volumes of water.(Mancl, 1989). Disadvantage are it requires contact time of 30 minutes for simple chlorination, turbidity (cloudy water) can reduce the effectiveness of chlorine, gives water a chlorine taste, may combine with precursors to form trihalomethane (THMs) and careful storage and handling of chlorine is required (Mancl, 1989).

1.7.8 Iodination

Advantages of iodine disinfection method are as follows: It does not require electricity, requires little maintenance, provides residual treatment and residual easy to measure. Disadvantages are as follows: Health effects of iodine udetermined, concentration affected by water temperature, gives water a slight straw color at high levels, gives water an iodine taste, not effective as an alicide (Mancl, 1989).

1.7.9 Characteristic a healthful and pleasant drinking water (Harner and Murphy ,1987).

Characteristic	Maximum level
Virtually colourless	15 c.u.[a]
Virtually odorless	3 t. o. n[b]
Low in total dissolved solids	500 ml/L[c] but not zero
	Low in heavy metals[d]
Low in hardness	7 gpg[e]
Low in nitrate nitrogen	10 mg/L
Low in dissolved iron	0.5 mg/L

Low in hydrogen sulfide	0.5 mg/L
Low in suspended materials	1- 5 NTU[f]
Low in microorganisms	1/100 ml[g]

[a]color unit

[b]Threshold Odor number

Milligrams per litre approximately the same as parts per million.

[e]Grain per gallon.

[f]Nephlometric turbidity unit.

[g]One coliform bacteria 100/milliliters for a monthly average, 4 per hundred ml as maximum per single example.

1.7.10 Characteristic of low quality drinking water (Vomcil *et al.,* 1993)

A good drinking water has none of the following characteristic:

* Astringent taste caused by sulfate.
* Metallic taste caused by iron.
* Salty taste caused by impurities of softener.
* Soda taste caused by dissolved salts.
* Medicinal taste caused by chlorinator.
* Rotten eggs odor caused by hydrogen sulfide.
* foul/ putrified caused by organic matter.
* rotten egg odor in hot water caused by magnesium rod in water heater.

Table 3: Microbiological guidelines of drinking water by WHO (1993), U. S. EPA (1996) and Sudanese Standards and Metrology Organization

Organisms	**Permissible value**
All water intended for drinking a. E. coli or thermotolerant coliform bacteria b. Pathogenic intestinal protoza	Must not be detected in 100 ml sample
2. Treated water entering the distribution system: a. E. coli or thermotolerant coliform bacteria b. Total coliform bacteria c. Pathogenic intestinal protoza	Must not be detected in 100 ml sample
.1 Treated water in the distribution system a. E. coli or thermotolerant coliform bacteria b. Total coliform c. Pathogenic intestinal protoza	Must not be detected in 100 ml sample Must not be detected in 100 ml sample. In case of large supplies where suffecient samples are examined, must not be detectable in 95% of samples examined throughout any 12-month period Must not be detected in 100 ml sample.

Table 4: Physical and chemical standards of drinking water by WHO (1993), U. S. EPA (1996) and Sudanese Standards and Metrology Organization (2002) SSMO.

Parameters	SSMO (2002)	WHO (1993) and U. S EPA
Colour	15 TCU	15 TCU
Taste and odor	Acceptable	3 t.o.n.
Turbidity	5 NTU	0 NTU
pH	6.5 – 8.5	6.5 – 8.5
Conductivity	350 microS/Cm	250 microS/cm
Antimony	0.004 mg/l	0.005 mg/l
Arsenic	0.007 mg/l	0.007 mg/l
Barium	0.2 mg/l	0.3 mg/l
Boron	0.5 mg/l	1.0 mg/l
Cadmium	0.003 mg/l	0.005 mg/l

Chromium	0.04 mg/l	0.05 mg/l mg/l
Copper	1.50 mg/l	2.0 mg/l
Cyanide	0.05 mg/l	0.05 mg/l
Fluoride	1.50 mg/l	1.50 mg/l
Lead	0.007 mg/l	0.007 mg/l
Manganese	0.50 mg/l	0.50 mg/l
Mercury (total)	0.0007 mg/l	0.001 mg/l
Molybdenum	0.05 mg/l	0.07 mg/l
Nickel	0.014 mg/l	0.014 mg/l
Nitrate as NO_3	45- 50 mg/l	45- 50 mg/l
Nitrite as NO_2	2.0 – 10.0 mg/l	10.0 mg/l
Selenium	0.07 mg/l	0.01 mg/l
Aluminum	0.2 mg/l	0.2 mg/l
Ammonia	1.5 mg/l	1.5 mg/l
Chloride	250 mg/l	250 mg/l

Residual chlorine	0.2 mg/l	0.3 - 0.5 mg/l
Hydrogen Sulfide	0.05 mg/l	0.03 mg/l
Iron	0.30 mg/l	0.20 mg/l
Sodium	20 mg/l	20 mg/l
Sulfate	250 mg/l	250 mg/l
Potassium	20 mg/l	20 mg/l
Magnesium	20 mg/l	20 mg/l
Zinc	3.0 mg/l	3.5 mg/l
Total Dissolved Solid	150 mg/l	150-500 mg/l
Total Hardness	180 – 200 mg/l	180 – 200 mg/l
Total alkalinity	500 – 1000 mg/l	500 mg/l

Chapter Three

3. Material and Methods

3.1 Study area:

Khartoum and Khartoum North were selected as study area, and twenty two centers were sampled. Water samples were collected from:

1. Water supply of two milling factory (One in Khartoum and the other in Khartoum North).
2. Water supply of two food factories (One in Khartoum and the other in Khartoum North).
3. Water supply of two mixed animal farms (One in Khartoum and the other in Khartoum North).
4. Water supply of two dairy farms (One in Khartoum and the other in Khartoum North).
5. Water supply of two milk processing factories (One in Khartoum and the other in Khartoum North).
6. Water supply of four bottled water factories (two from Khartoum and two from Khartoum North).

7. Tap water supply of two public hospitals (One from Khartoum and the other from Khartoum North).
8. Tap water supply of two private hospitals (One from Khartoum and other in Khartoum North).
9. Tap water supply of four residential houses (Two from Khartoum and the others from Khartoum North).

Table 5: Locations and water sample sources collected from Khartoum North and Khartoum area

Location and sample source	No. of sample examined
Khartoum North raw well water:	6x3
1. Milling factory	1x3
2. Food factory.	1x3
3. Dairy farm.	1x3
4. Milk processing factory.	1x3
5. Bottled water factory	2x3
Khartoum North treated well water:	6x3
1. Milling factory	1x3
2. Food factory.	1x3
3. Dairy farm.	1x3
4. Milk processing factory.	1x3
5. Bottled water factory	2x3
Khartoum North treated tap water:	5x3
1. Mixed animal farm	1x3
2. Public hospital	1x3
3. Private hospitals	1x3
4. Residential houses	2x3
Khartoum area raw well water:	6x3
1. Milling factory	1x3
2. Food factory.	1x3
3. Dairy farm.	1x3
4. Milk processing factory.	1x3
5. Bottled water factory.	2x3
Khartoum area treated well water:	6x3
1. Milling factory	1x3

2. Food factory.	1x3
3. Dairy farm.	1x3
4. Milk processing factory.	1x3
5. Bottled water factory.	2x3
Khartoum area treated tap water	5x3
1.Mixed animal farm .	1x3
2. Public hospital	1x3
3. Private hospitals	1x3
4. Residential houses	2x3

3.2 Sample types:

Samples were collected for:

a. Bacteriological examination to check the presence of bacterial contaminants.

b. Physical and Chemical examination to check the presence of chemical contaminants.

3.3 Sampling techniques:

Water sample was collected aseptically in sterile bottle. The opening of the tap was cleaned and sterilized by alcohol and flaming.

The tap was then opened and first stream was discarded and after 2 minutes, sample was collected in sterile bottle. The bottle was tightly closed and immediately transported to laboratory for bacteriological and chemical analysis. The bacteriological and chemical analysis were carried out in Al Murgan Central Laboratory, Soil Science dept. Laboratory (Faculty of Agriculture, University of Khartoum) For analysis of trace minerals

contaminants and Laboratory of Institutes of Environmental Studies, University of Khartoum for the analysis of heavy metals.

3.4 Bacteriological techniques:

Two bacteriological techniques were used to estimate the total count of bacteria and total coliform count.

3.4.1 Total count:

The membrane filter (MF) heterotrophic plate count method described by Greenberg *et al*. (1998) was followed to estimate total bacterial populations in water. Sample volume (5ml) was passed through a membrane filter with a pore size 0.43 µm which is small enough to retain the bacteria present in the water sample. The membrane filter was then placed on absorbent pad saturated with culture medium selective for heterotrophic bacteria growth in Petri dish. The Petri dish containing the membrane filter and the pad was incubated upside down at 35°C. After 24 hours incubation, the developed colonies were counted. The results were expressed as colonies /5ml sample.

3.4. 2 Total coliform count: The medium used for total coliform count was M.Endo Type. The medium is composed of :

Tryptose or polypeptone	10.0 gram
Thiopeptone or Thiotone	05.0 gram
Casitone or Trypticase	01.5 gram
Yeast extract	12.5 gram
Lactose	12.5 gram

Sodium chloride	05.0 gram
Dipotassium hydrogen phosphate	04.375 gram
Potassium dihydrogen phosphate	01.375 gram
Sodium lauryl sulphate	00.05 gram
Sodium desoxycholate	00.10 gram
Sodium sulphate	02.10 gram
Basic Fuchsin	01.05 litre
Agar (optional)	15.00 gram
Reagent grade water	01.00 Litre

The medium was used to prepare pad saturated with M. Endo medium. Membrane filter paper procedures:

Sterile membrane filter was placed by sterile forceps over porous plate of sterile funnel receptacle then the funnel was carefully placed on stand. Water sample (5ml) was poured into the funnel under partial vacuum. Then the surface of the funnel was rinsed with small amount of sterile distilled water. Then the filter paper was placed on the prepared pad saturated with M. Endo medium in Petri dish. The Petri dish containing the membrane and the pad was incubated upside down at 35°C. After 24 hours incubation, the coliform colonies appeared red with metallic golden sheen. The appeared colonies were counted. The results were expressed as colonies/5ml sample.

3.5 Physical and chemical techniques:

The physical and chemical contaminants analysis methods and procedures were adopted from Greenberg *et al*. (1998).

3.5.1 Temperature:

1- Temperature was measured in place when samples was taken because a water sample is soon reached the temperature of the surrounding air , glass thermometer, mercury filled with 0.1˚C graduation was immersed in the water sample for at least one minute till the liquid column in the thermometer stopped moving.

2- The reading was recorded to the nearest 0.1˚C

3.5.2 Odor:

The odor was estimated by direct smelling.

3.5.3 pH:

The pH was measured by direct reading using pH meter. The pH was measured as follows:

1- At first the apparatus was standardized as Greenberg *et al*. (1998) described. The apparatus electrodes and small beaker were rinsed with portion of the sample. Sufficient amount of the sample was poured into the beaker to allow the tips of the electrode to be immersed to 2 cm height and 1 cm away from the sides and bottoms of the beaker.

2- Temperature was checked so as not to be too high. Then the pH meter was turned on.

3- The temperature and pH of the water sample were recorded.

3.5.4 Electric conductivity:

Procedure:

1- Water sample conductivity was measured by rinsing out the conductivity cell with at least three portions of the sample,

2- The temperature of the a portion of the sample was adjusted to 20°C $\pm$ 0.1°C.

3- The conductivity cell containing the electrodes was immersed in a sufficient volume of the sample for liquid level to be above the vent holes in the cell. It was noticed that there was no air bubble clinging to the electrode and the cell was not closer than 2 cm to the sides and bottom of the container.

4- The temperature of the sample was observed and recorded to the nearest 0.1ºC and then the meter turned on and the reading was recorded. The measuring unit was millisiemens per meter (1mS/m = 10 μs/cm = 10 μmhos).

3.5.5 Turbidity:

The water turbidity was measured by nephlometric method. This method was based on a comparison of the intensity of light scattered by the sample under defined condition with the intensity of light scattered by standard reference suspension under the same condition.

The turbidity was measured by using HACH 2000 Turbidity meter and the results were reported in Nephlometric turbidity unit (NTU)

3.5.6 Total suspended solids:

The total suspended solids (TSS) applies to the dry weight of the material that is removed from a measured volume of water sample by filtration through a standard filter.

Procedure:

1. The filter disc was placed on the filter holder, the filter holder was assembled in suction flask apparatus and vacuumed by vacuum source.
2. The filter disc was washed by distilled water and vacuumed for 2-3 minutes after the water passed through the filter. The filtrate was discarded.
3. The filter paper was removed from the filter funnel and placed on a supporting surface in a drying oven at 103 – 105 C for 1 hour.
4. The filter paper was cooled in a desiccators and weighed in analytic balance.
5. The above was repeated till the weight loss between two successive series of operations was less than 0.5 mg.
6. Filter paper was stored into desiccators until required and weighed (W_1).
7. The filter was placed in the filter holder and it assembled in suction flask and vacuum was applied.
8. The sample was shaken vigoursly and 100ml sample was measured and then poured into the funnel, washed with distilled water, then dried in drying oven at 103–105°C.

9. Then cooled in a desiccators and weighed (W_2).
10. The total suspended solid equal $W_2 - W_1$.

3.5.7 Calcium:

Principle method of calcium measurements in water sample was by EDTA Titrimetric method. The general principle is that when adding ethylene diamine tetra acetic acid (EDTA) solution to water sample containing calcium and magnesium ions, it reacts with the calcium before the magnesium. Calcium can be determined in the presence of magnesium by EDTA titration, the indicator used is one that reacts with calcium only. Indicator solution gives a colour change when all of the calcium has been complexed by EDTA at pH of 12-13.

Procedure:

1. A colour comparison blank was prepared by placing 50 ml of the distilled water in a white porcelain dish.
2. Then the sample for titration was placed in 50 ml in a white porcelain dish.
3. Two ml of NaOH solution were added to both the sample and the comparison blank and were stirred, the pH was adjusted between 12 and 13.
4. Two drops of Murexide indicator solution was added to the blank and stirred then one to two drops of EDTA titrant from the burette were added each time while stirring till the colour turned from red to an orchid purple.

5. The burette reading was recorded.
6. The blank was kept to be used as colour reference comparison.
7. The sample was titrated as described for the blank in step 4.
8. The burette was read and the volume of EDTA titrant used by subtracting the burette reading from the reading of step (5). Calcium concentration was calculated as follows:

$$Ca = A \times C \times 400.8/\text{ml sample}$$

Where:

A=Volume of EDTA titrant used for titration of sample (ml)

C = ml of standards calcium solution /ml of EDTA titrant. The results were recorded as mg/ litre.

3.5.8 Total hardness:

The total hardness of water sample was measured by EDTA Titrimetric method as described by Greenberg *et al.* (1998).

Procedure:

1. An mount of 25 ml of the sample was diluted to 50 ml EDTA titrant and titration was completed within 50 ml with distilled water in a porcelain dish.
2. Two drops of Erichrome Black T indicator solution was added.
3. Standards EDTA titrant was added slowly with continuous stirring till the last reddish tings disappeared from the solution and the solution became normally blue.

4. A distilled water blank was titrated of the same volume as the sample, identical amount of buffer, inhibitor, and indicator were added.
5. Two drops of Murexide indicator solution was added to the blank and stirred then one to two drops of EDTA titrant from the burette were added each time while stirring till the color turned from red to an orchard purple.
6. The burette reading was recorded.
7. The bank was kept to be used as color reference comparison.
8. The sample was titrated as described for blank in step 5.
9. The burette was read and the volume of EDTA used was determined by subtracting the burette reading of step (6). Calculation:

Total hardness = (T – S) x C x 1000/volume of sample, ml

Calcium hardness = A x C x 1000/ml sample, ml

Where:

T= volume of EDTA for titration of the total hardness sample.

S = volume of EDTA for titration of the blank (ml)

A= volume of EDTA for titration in the calcium procedure (ml).

C= ml of standards calcium solution/ml of EDTA titrant.

Results were reported as mg $CaCO_3$/litre.

3.5.9 Magnesium:

Magnesium was determined by subtracting the calcium hardness from total hardness the remained amount contributed to magnesium (Greenberg *et al*. 1998).

Mg = Total Hardness – Calcium hardness

3.5.10 Alkalinity:

Alkalinity was determined by titration of the sample with standard solution of a strong acid. The method was that described by Greenberg *et al*. (1998).

The procedure:

1. Amount of 100 ml water sample was mixed with two to three drops of phenolphthalein indicator in the porcelain basin. If no color was produced the alkalinity to phenolphthalein was zero. If the sample turned pink or red, the alkalinity was determined by titration with standard acid until pink colour disappeared. In either cases the determination was continued by using the sample to which phenolphthalein had been added.
2. A few drops of methyl orange indicator were added, and if the sample was orange without the addition of acid, the total alkalinity was zero and if the sample turned yellow titration with standards acid was done till the first perceptible color changed towards orange took place.
3. The determination by means of mixed indicator was done in the same way as with methyl orange. The following color responses were yielded by the mixed indicator: Above pH 5.2, greenish blue, pH 5.0, light blue with lavender grey; pH 4.8, light pink – grey with a bluish cast; pH 4.6, light pink. Another way to provide a standards end-point was to prepare buffer solutions to which indicators were added in the same amount as in an alkalinity titration.

Calculation:

Phenolphthalein alkalinity as $CaCO_3$

$P = 100000 \times A \times M/V$ mg/litre.

Total alkalinity as $CaCO_3$

T= 100000 x B x M/V mg/litre.

Where,

A= Volume of standard acid solution (ml) to reach the phenolphthalein end point of pH 8.3

B= Volume of standard acid solution (ml) to reach the end point methyl orange or mixed indicator

M= Concentration of acid (mol/litre)

V= Volume of the sample.

Results were reported in mg/l calcium carbonate.

3.5.11 Chloride:

Chloride was determined in a neutral or slightly alkaline solution by titration with standard silver nitrate using potassium chromate as indicator. Silver chloride was quantitatively precipitated before red silver chromates was formed. The method used was that described by Greenberg *et al.* (1998).

The procedure:

1. Sample of 100 ml was measured into porcelain dish and pH was adjusted to about 8.0.
2. One ml of potassium chromate indicator solution was added and stirred.

3. The sample were titrated with silver nitrate solution with constant stirring until slight reddish coloration persists.
4. Steps 1 to 3 was repeated on a 100 ml distilled water blank to allow for the presence of chloride in any of the reagents and for the solubility of silver chromate.

Calculations:

$$\text{Chloride as } CI^- = (V_1 - V_2) \times 1000 / \text{Volume of sample}$$

Where

$V_1 =$ volume of silver nitrate required by the sample (ml)

$V_2 =$ volume of silver nitrate required by the blank (ml)

Results was reported in mg/litre chloride.

3.5.12 Residual chlorine:

Hach OV-vis spectrophotometer stored program1450 selected wavelength 530 nm + DPD Free chlorine reagent powder pillows + DR/4000 – 1 – inch cell adapter + Beaker (50 ml) + water sample.

Chlorine in water sample as hypochlorus acid or hypochlorine ion (free chlorine or free available chlorine ion) immediately reacts with DPD (N,N-diethyl-P-phenylene diamine) indicator to form pink colour which is propotional to the chlorine concentration in water sample as follows:

$$Cl_2 + H_2O = H^+ + CI^- + HO\,CI$$

$$DPD + Cl_2 = \underset{\textbf{Red colour}}{DPD} + 2\,CI^- + H^+$$

DPD and Hach Method no. 8021 which was adapted and described by Greenberg *et al.* (1998) was used for determination of residual chlorine..

3.5.13 Nitrate:

The Devarda's alloy method described by Greenberg *et al*. (1998) was used. The method, involves oxidation, distillation and titration.

Procedure:

1. The distillation flask, splash head and the condenser were thoroughly cleaned to free it from possible condensed ammonia.
2. The water sample 200 ml was added into the flask.
3. Ten ml of 10 mol/litre sodium hydroxide (NaOH) were added, and the distillation flask content was evaporated to 100 ml.
4. The residue was allowed to cool, at the end of the distillation procedure for the analysis for ammonia.
5. To the cooled residues, sufficient amount of ammonia free water was added to bring the volume to 350 ml and the flask was immediately connected to the condenser.
6. After 5 minutes the distillation was started, the lower end of the delivery tube from the condenser kept below the surface of the liquid in the receiver throughout the distillation.
7. About 50 ml of boric acid solution were placed in the receiver and distilled at the rate of about 10 ml/minute.

8. As the colour changed by the absorbent solution, titration was done with 0.00714 mol/litre hydrochloric acid, the distillation was continued until one drop of the standard acid solution produced a permanent pink color in the solution.
9. The receiver was removed from the apparatus after titration was completed and before the source of the heat was withdrawn.
10. Blank determination was carried out as appropriate. For each sample, the final titration figures were corrected for any ammonia in the reagent used.

Calculation:

$$\text{Nitrate nitrogen: (as N)} = \frac{(a-b)x\ 100}{v} - n \quad \text{mg/litre}$$

Where

a= volume of 0.00714 mol/litre acid used for titration of the sample.

b= volume of 0.00714 mol/litre acid used for titration of the blank.

V= volume of the undiluted sample (ml).

n= concentration of nitrite nitrogen in mg/litre N, determined separately.

The result was reported in mg/litre and it was rounded to two significant figure.

3.5.14 Potassium (K):

The colorimetric method of analysis was used as described by Greenberg *et al*. (1998).

Procedure:

1. Hundred ml of water sample was taken and its K content was concentrated by evaporation, until about only 5 ml remain. The concentrated sample was transferred to a 25 ml centrifuge tube and made up to 10.0 ml with deionized distilled water.
2. Both time and temperature were kept constant for all samples and standards, in a series of tests ±5 ℃ and ±15 minutes.
3. One ml of 1 mol/litre nitric acid and 5 ml of the trisodium cobalt nitric solution were added and set aside for 2 hours at room temperature.
4. The mixture was centrifuged for 10 minutes, the liquid was poured off and the precipitate was washed with nitric acid and stirred to ensure contact between the precipitate and the wash solution.
5. It was centrifuged again for 10 minutes. The liquid was poured off and 10 ml of standard potassium dichromate solution were mixed with 5 ml concentrated sulfuric acid.
6. The mixture was cooled at room temperature and then made up to 100 ml with deionized distilled water.

7. The standards were prepared as follows: Portion of 1, 2, 3, 4, 5, 6 and 7 ml of the standard potassium solution was pipetted into a series of 25 ml centrifuge tubes, and made up to 10 ml with deionized distilled water. All tubes were treated as mentioned in step 3 and 4 to obtain colour standards containing 1.00 to 7.00mg K.
8. The spectrophotometer (Hach 2000) was used to measure the absorbance of the standards and the samples at wavelength (λ) 520 nm.
9. The color of the sample was compared to the colour of the standards and the closest colour to the standards was selected to obtain the concentration of sample.

Calculation :

Potassium = mg K x 1000/ ml sample

The results were reported in mg/litre.

3.5.15 Sodium:

The Principle of Sodium analysis: Sodium is precipitated as sodium zinc uranyle acetate hexhydrate, $NaC_2H_3O_2$-$Zn(C_2H_3O_2)_2$ -$3UO_2$ $(C_2H_3O_2)_2$ – $6H_2O$, by adding large volume of zinc uranyl acetate reagent, previously saturated with the sodium salt, to a small volume of concentrated sample.

Procedure:

1. All suspended solids removed from 50-100 ml of sample by filtration.

2. A portion of clear sample containing less than 8 mg sodium was selected. This was about as 2 ml of very salty water or as much as 30 ml of relatively salt – free fresh water. The measured portion was pipetted into borosilicate glass beaker of appropriate size.
3. Evaporation over steam bath to dryness was done.
4. The residue was cooled to room temperature and 1.0 ml distilled water was added and stirred with a glass rod to dissolve all residue.
5. Zinc uranyl acetate reagent was added in the ratio of 10 ml of reagent for each 1.0 ml of distilled water used to dissolve the residue. The beaker was covered and let to stand for one hour, and stirred periodically to prevent the formation of a super saturated solution.
6. An apparatus for suction filtration using a medium porosity fritted glass crucible was arranged.
7. The content of the beaker were poured into the crucible and filtered under suction. The beaker was rinsed at least five times with 2 ml portions of the zinc uranyl acetate reagent, and the content poured into the crucible, after the last rinse the suction was maintained for several minutes to remove all possible traces of the reagent.
8. Suction was maintained while all contents of the crucible were washed five times with 2 ml portions of the ethyl alcohol wash

solution. The washing was concluded with three small portions of diethyl ether.

9. Suction was continued for a few minutes until the ether evaporated and the precipitate in the crucible was dry.
10. When salt was crystallized on the outside of the crucible, it was wiped clean with a soft cloth or tissue.
11. The crucible and content were weighed and the weighing were repeated after 15 min. interval and a third time after a further 15min. to check on the constancy of weight (W_1).
12. The crucible was returned to suction apparatus, suction was applied and warm distilled water in portions of approximately 10 ml, was used and total of about 100 ml warm distilled water was added to dissolve all traces of sodium zinc uranyl acetate. The crucible was dried with ethyl alcohol wash solution and diethyl ether as in step 11 above and reweighed as in step 10 (W_2).
13. The weight obtained in step 12 was subtracted from that of step 11 and this represents the weight of the sodium zinc uranyl Acetate.

Calculations:

$$\text{Sodium} = A \times 14.95/ \text{ ml sample}$$

$$A = (W_2 - W_1)$$

Where

A= the weight of the sodium zinc uranyl acetate (mg) = (W_1-W_2).

Results were reported in mg/litre.

3.5.16 Sulfate:

Principle of sulfate analysis:

Sulphate in sample react with barium chloride to form a precipitate of barium sulfate. The amount of turbidity formed is directly in proportion to the amount of sulfate.

Procedure:

1. Fifty ml of water sample were placed on the porcelain dish. One to two ml of buffer solution (which was prepared from : 55 ml of conc. HCl + 400 ml of distilled water + 310 ml of 2-aminoethanol 5 g of magnesium disodium ethylenediamine tetra acetate and diluted to 1 litre with distilled water) were added . The pH was adjusted to 10.0.
2. Two drops of indicator solution (which was prepared by grinding 0.5 g of Eriochrome Black T together with 100 g of NaCl and dissolved in distilled water) were added.
3. Titration was conducted slowly with EDTA standard titrant and stirred continuously till the last reddish tings disappeared and the sample became blue. The titration was completed within 5 minutes of the addition of buffer. The amount of EDTA used was recorded.
4. Step 1 to 3 were repeated using 25 ml of sample diluted to 50 ml with distilled water.

5. Hardness was calculated as Ca CO_3 mg/litre.
6. Hundred ml of sample were measured and were poured into a beaker; the alkalinity was neutralized to pH 4.5 with 1 mol/litres HCl or HNO_3.
7. The sample was transferred to the boiler to expel the carbon dioxide, Ten ml of barium chloride standard solution was added to the boiling sample. The volume was reduced to less than 100 ml and then removed from the heat and allowed to cool.
8. The sample was transferred with rinsing to 100 ml graduated cylinder and made up to 100 ml mark with distilled water, any precipitate was allowed to settle.
9. Fifty ml was poured of the clear supernatant into a porcelain dish, 2ml of buffer solution were added and the pH was adjusted to 10.0 ± 0.1.
10. Two drops of the indicator solution were added.
11. Titration was done slowly with EDTA standard and stirred till the sample became blue. Then titration completed within 5 minutes of the addition of buffer. The amount of EDTA used was recorded.

Calculation:

First calculation:

The hardness was calculated from the result of the titration at step 3 of the procedure as follows:

Hardness = 1000 x H/V_1

Where

H = Volume of titrant used in step 3 of procedure (ml)

V_1 = Volume of sample used in titration as in step 3 (ml).

Results were reported in mg/litre $CaCO_3$.

Second step:

$$\text{Hardness} + BaCl_4 = 1000 \times T / V_2$$

Where

T = volume of titrant used in step 11 of the procedure.

V = volume of sample used in the titration at step 11 (ml).

$BaCl_4$ = volume of barium chloride that did not combine SO_4 (ml).

Results were reported in mg/litre Ca CO_3

The final part of the calculation was add to the concentration of the barium chloride solution (1000 mg/litre) to substract the result of the second titration and to convert the result to mg/litre SO_4.

Hardness (mg/litre) +1000 – (hardness + $BaCl_4$) × 0.96 = mg/litre SO_4 .

3.5.17 Iron :

Iron in water was estimated by phenanthroline method as described by Greenberg *et al*.(1998).

a. Iron Total:

Procedure:

1. The sample was mixed thoroughly and 50 ml were measured into 125 ml Erlenmeyer flask.
2. Two ml of conc. HCl and one ml of NH_2 OH. HCl solution were added.
3. A few glass beads were added and heated to boiling.
4. To ensure dissolution of all the iron boiling was continued until volume was reduced to 15 – 20ml, cooled to room temperature and transferred to a 50 ml or 100 ml volumetric flask or Nessler tube.
5. Ten ml of $NH_4 C_2 H_3 O_2$ buffer solution and 4 ml phenanthroline solution were added and mixed thoroughly and diluted to mark with water and allowed to stand for a minimum of 10 minutes for maximum color development.

b. Dissolved Iron :

Procedure:

1. Immediately after collection the water sample was filtered through a 0.45μm membrane filter into a vacuum flask containing 1 ml concentration HCl/100 ml sample.
2. Filtrate was analyzed for total dissolved iron and /or dissolved ferrous iron.

3. Suspended iron was calculated by subtracting dissolved iron from total iron.

3.5.18 Fluoride:

The concentration of fluoride in water sample was measured by Spands method as described by Greenberg *et al*. (1998):

Principle: The spand colorimetric method is based on the reaction between fluoride and zirconium-dye lake.

Reagents:

1. Deionized or distilled water.
2. Fluoride standards solution which was prepared by dissolving 0.221 g of analytical grade anhydrous sodium fluoride, NaF in distilled water and dilute to 1 litre (1 ml is equivalent to 100 micrograms F.).
3. Working standards of 10 micrograms F^- per 1.0 ml. which should be prepared just before the analysis.
4. Spand solution: 0.958g of spands (sodium 2-parasulfophenylazo)-1,8-dihydroxy-3,6-naphthalene disulfonate was dissolved in distilled water and diluted to 500 ml.
5. Acid-zirconyl reagent: 130 mg 0f zirconyl chloride octahydrate, $zroCl_2.8H_2O$, was dissolved in 25 ml distilled water and 350 ml of concentrated hydrochloric acid was added and the mixture was diluted to 500 ml with distilled water.

6. Acid-zirconyl/spands reagent: Equal quantities of spand solution and acid-zirconyl reagent were mixed

Procedures:

1. Preparation of standards curve. The fluoride standards in the range of 0 to 1.4 mg F^-/litre was prepared by diluting appropriate quantities of standard fluoride solution to 50 ml with distilled water. Five ml of each of the spands solution was pipetted and the acid –zirconyl reagent or 10.00 ml of the mixed acid–ziroconyl/spands, were pipetted and mixed well. Contamination was avoided. The photometer was set to zero absorbance with reference solution and the absorbance reading of the standards was obtained. Curve of the relationship between mg fluoride and absorbance was plotted.
2. Sample pretreatment. Residual chlorine was removed if found in the sample by adding 1 drop (0.05 ml) NaAsO solution /0.1 mg residual chlorine and mixed
3. Colour development. A fifty ml sample or a portion diluted to 50 ml with distilled water was used, the temperature was adjusted as in the standards curve. Five ml each of spands solution and acid – zirconyl reagent were added. The absorbance was read, after setting the reference point of the photometer at zero. If the the absorbance falls beyond the range of the standard curve the procedure was repeated using a diluted sample.

Calculations:

$$\text{Flouride} = A/\text{ml sample} \times B / C$$

Where

^{-}F =A determined from the plotted curve (micrograms).

B= Final volume of diluted sample (ml).

C= Volume of diluted sample used for color development.

Results were reported in mg/litre .

Chapter Four

4. Results

4.1 Survey:

Water samples were collected from twenty two sources, eleven from Khartoum North area and eleven from Khartoum area. Samples from Khartoum North area were well water of Milling, Food, Dairy, Milk processing and bottled water 1 and 2 factories and sample of tap water from mixed animal farm, public and private hospitals and residential houses.

Samples from Khartoum area were well water of Milling, Food, Dairy , Milk processing and bottled water 1 and 2 factories sample of tap water from mixed animal farm, public and private hospitals and residential houses as shown in table 5.

Three water samples were collected from each source.

4. 2. Khartoum North area:

4. 2.1 Microbial contaminants:

4.2.1.1 Total count and total coliform count

The mean value of total bacterial count in raw well water samples collected from Khartoum North area varied from 70.67 to 480.33/5ml (Table, 6). The total coliform count of raw well water samples collected from Khartoum North area were zero except for food and milling factory which showed mean value of 0.33/100 ml (Table, 6) .

The highest value of total count were observed in well water sample collected after treatment from milling factory and dairy farm 834.00 and 824.33/100 ml respectively as shown in Table 6.

After treatment process the total coliform mean value of well water samples collected from dairy farm and milk processing factory was 0.67/5ml. The total coliform counts of the treated tap water collected from Khartoum North area were zero.

The highest total count values were recorded in tap water sample collected from residential house and public hospital 387.67 and 309.00/5 ml respectively as shown in Table 7.

4.2.2 Physical contaminants:

4.2.2.1 Turbidity

The turbidity mean value of well water samples collected from Khartoum North area ranged from 65 to 145 NTU. After treatment process the turbidity values decreased and the values only ranged from 5.0 to 26.0 NTU, and the highest turbidity were noticed in treated water samples collected from food factory and bottled water factory 26.0 and 25.5 NTU respectively as shown in table 8.

The Turbidity mean value of the treated tap water collected from Khartoum North area were ranged from 7.0 to 44.0 NTU as shown in Table 9.

4.2.2.2 Total dissolved solids

The total dissolved solids mean value of well water samples collected from Khartoum North area varied from 325 to 660 mg/l. After treatment

Table 6: Total bacterial counts and coliform count of raw and treated well water collected from Khartoum North area

Location of collected samples	Sample source	Parameter mean value			
		Total count/5ml		Coliform count/100ml	
		Raw	Treated	Raw	Treated
Milling factory	Well	181.67	834.00	0.33	1.00
Food factory	Well	480.33	088.00	0.33	0.00
Dairy farm	Well	070.67	824.33	0.00	0.67
Milk Processing factory	Well	146.33	685.67	0.00	0.67
Bottled Water factory1	Well	384.33	168.67	0.00	0.00
Bottled Water factory2	Well	187.67	143.00	0.00	0.00

Table 7: Total Bacterial counts and coliform count of treated tap water collected from Khartoum North area

Location of collected samples	Sample source	Parameter mean value	
		Total count/5ml	Total count/5ml
Mixed animal farm	Tap	000.67	0.00
Public hospital	Tap	309.00	0.00
Private hospital	Tap	116.67	0.00
Residential house1	Tap	002.67	0.00
Residential house 2	Tap	387.67	0.00

process the total dissolved solids mean values decreased and the values ranged from 80 to 105 mg/l (Table, 8).

The total dissolved solids mean value of the treated tap water collected from Khartoum North were ranged from 105 to 550 mg/l (Table, 9).

4.2.2.3 pH

The pH of well water samples collected from Khartoum North area ranged from 7.5 to 7.8 (Table,8).

The highest pH (7.5) was that of well water samples collected after treatment process from Khartoum North area and the lowest pH value was 6.8 for bottled water factory 2 (Table, 8).

The pH of the treated tap water collected from Khartoum North area ranged from 7.5 to 7.8 (Table, 9).

4.2.2.4 Electrical conductivity

The electrical conductivity (EC) of well water samples collected from Khartoum North area ranged from 220 to 500 micromhos/cm (Table, 8). After treatment the electrical conductivity mean values decreased and ranged from 105 to 195 micromhos/cm (Table,8).

The electrical conductivity (EC) of treated tap water samples collected from Khartoum North area ranged from 85 to 205 micromhos/cm (Table,9).

4.2.2.5 Total suspended solids

Total suspended solids were not detected in any of the samples examined in Khartoum North area (Table, 8 and 9).

4.2.2.6 Odor and taste

Odor/taste were within acceptable range in all water samples collected from Khartoum North area (Table 8 and 9).

4.2.3 Chemical contaminants:

4.2.3.1 Anions contaminants:

4.2.3.1.1 Total alkalinity

The total alkalinity of raw well water samples collected from Khartoum North area showed considerable differences. The highest value was that of bottled water factory 2 (560mg/l), and the lowest value was that of milling factory (180 mg/l). After treatment the total alkalinity of raw well water samples collected from Khartoum North area was not affected by treatment process and varied from 180 to 560 mg/l (Table, 10).

The total alkalinity of the treated tap water samples collected from Khartoum North area had highest value of 160 mg/l in private hospital water and the lowest value of 50 mg/l of residential house 2 water as shown in Table 11.

4.2.2.1.2 Total hardness

Raw well water samples collected from Khartoum North area were very hard and showed values above 180 mg/l as shown in (Table 10) and total hardness of raw well water samples collected from Khartoum North area ranged from 180 to 200 mg/l. After treatment process the total

hardness of well water decreases considerably and values ranged from 60 to 80 mg/l as shown in table 10.

Total hardness of treated tap water samples collected from Khartoum North area considered moderately soft and ranged from 30 to 85 mg/l as shown in table 11.

4.2.2.1.3 Fluoride

The fluoride concentration of raw well water samples collected from Khartoum North area ranged from 1.2 to 3.5 mg/l. the highest value was that of bottled water factory 1 (3.5 mg/l), and the lowest value was that of Milk processing factory 1.2 mg/l as shown in (Table, 10). After treatment fluoride concentration of well water decreased and ranged from 0.01 to 0.3 mg/l, Fluoride concentration of treated tap water samples of Khartoum North area reported was zero for all water samples examined as shown in (Table 11).

3.2.2.1.4 Nitrate

The Nitrate concentration in raw well water samples collected from Khartoum North area ranged from 3.0 to 8.2 mg/l as shown in table 10.

After treatment the nitrate concentration of well water considerably ranged from 0.0 to 6.0 mg/l. The highest value was that of treated well food factory (6.0 mg/l) and the lowest value was that of bottled factory 2 and milling factory (0.0 mg/l) as shown in table 10.

The nitrate concentration in treated tap water samples collected from Khartoum North area ranged from 0.12 to 6.0 mg/l (Table, 11).

4.2.1.1.5 Chloride

The chloride concentration of well water samples collected from Khartoum North area ranged from 150 to 350 mg/l. After treatment process the chloride concentration of well water decreased significantly and the highest chloride concentration noticed in treated well water of milling factory (177 mg/l) and the lowest concentration was detected in the treated well water of bottled factory 2 (180 mg/l) (Table 10).

The chloride concentration in treated tap water collected from Khartoum North area varied and the highest concentration recorded was that of residential house 2 (105 mg/l), the lowest noted was that of private hospital (0.7 mg/l) as shown in table 11.

3.2.1.1.6 Sulfate

The sulfate concentration in raw well water samples collected from Khartoum North area ranged from 160 to 180 mg/l. After treatment process the sulfate concentration of well water decreased and the highest sulfate concentration reported was that of milling factory and the lowest sulfate concentration was observed in food factory treated well water (5.0 mg/l) (Table 10).

The sulfate concentration of treated tap water collected from Khartoum North area varied from 10.0 to 16.5 mg/l (Table, 11).

4.2.2.1.7 Residual chlorine

The Chlorine which was added as disinfectant in well water collected from Khartoum North area ranged from 0.01 to 0.12 mg/l (Table, 10).

No residual chlorine was detected in treated tap water collected from Khartoum North area (Table 11).

4.2.3.2 Cations contaminants:

4.2.3.2.1 Sodium

The sodium concentration of raw well water samples collected from Khartoum North area ranged from 35.0 to 74.0 mg/l. After treatment the highest concentration of sodium was that recorded in water samples collected from dairy farm (74.0 mg/l) and the lowest sodium concentration was that recorded in samples collected from bottled water factory 1 (2.5mg/l) as shown in table 12.

Sodium concentration of treated tap water samples collected from Khartoum North area ranged from 12.4 to 18.2 mg/l as shown in table 13.

3.5.1.1.2 Potassium

The potassium concentration of raw well water samples collected from Khartoum North area ranged from 14 to 28 mg/l. After treatment process the highest potassium concentration was that recorded in water samples collected from milling factory (5.5 mg/l) and the lowest potassium concentration was estimated in treated well water samples collected from bottled factory 2 (0.12 mg/l) as shown in table 12.

Potassium concentration of treated tap water samples collected from Khartoum North area ranged from 0.21 to 2.19 mg/l as shown in table 13.

4.2.3.2.3 Iron

Iron concentrations of raw well water samples collected from Khartoum North area ranged from 0.12 to 0.18 mg/l. After treatment process iron concentrations decreased and appeared to be absent from most of the treated well water samples examined such as those of milling factory , milk factory and Bottled factory 2 as shown in table 12.

Iron concentrations of treated tap water samples collected from Khartoum North area ranged from 0.13 to 0.18 mg/l as shown in table 13.

4.2.3.2.4 Calcium

Calcium concentration of raw well water samples collected from Khartoum North area ranged from 65.0 to 75.0 mg/l. The calcium concentration of raw well water was lowered significantly by treatment.

After treatment process calcium concentration ranged from 5.9 to 25.0 mg/l as shown in table 12.

Calcium concentration of treated tap water collected from Khartoum North area ranged from 12.10 to 45.2 mg/l. The highest concentration was that recorded in water samples collected from public hospital (45.2 mg/l) and lowest concentration was that measured in tap water samples collected from residential house 1 (12.10 mg/l) as shown in table 13.

4.2.2.2.5 Magnesium

Magnesium concentration of raw well water samples collected from Khartoum North area ranged from 4.5 to 18.5mg/l. After treatment process magnesium concentration varied and 20.0mg/l was recorded for the samples collected from Dairy farm and 4.0 mg/l was observed in treated well water samples of bottled water factory 2 as shown in table 12. This revealed that treatment had no effect on magnesium content of well water of Khartoum North area.

Magnesium concentration of treated tap water samples collected from Khartoum North area ranged from 3.9 to 14.58 mg/l as shown in table 13.

4.3 Khartoum area:

4.3.1 Microbial contaminants:

4.3.1.1.Total count and total coliform count:

The total counts in well water samples collected from Khartoum area ranged from 0.67 to 184.33/5 ml. Count of 0.33/100 ml coilform count were noticed in well water samples collected from food factory (Table, 14).

After treatment of well water total count increased in all locations and no coliforms were present (Table,14).

In treated tap water samples collected from Khartoum area the highest total count were 387and 309/5ml in water samples collected from residential house 2 and public hospital respectively. No coliforms were present (Table, 15).

4.3.2 Physical contaminants:

4.3.2.1 Turbidity

The turbidity mean values of well water samples collected from Khartoum area ranged from 105 to 185 NTU. After treatment process the turbidity value decreased and the value only ranged from 5.0 to 7.5 NTU were noticed and the highest turbidity in well water after treatment was that of food factory and dairy farm (7.5 NTU) (Table 16).

The turbidity mean value of the treated tap water collected from Khartoum area ranged from 8.0 to 46.0 NTU (Table17).

4.3.2.2 Total dissolved solids

The total dissolved solids mean value of well water samples collected from Khartoum area observed were varied from 355 to 650 mg/l. After treatment process the total dissolved solids mean value of well water samples collected from Khartoum area decreased and ranged from 105 to 260 mg/l (Table 16).

The total dissolved solids mean value of the treated tap water collected from Khartoum area ranged from 200 to 295 mg/l (Table 17).

4.3.2.3 pH

The pH of well water samples of Khartoum area ranged from 7.6 to 8.0 The highest pH value recorded (8.0) was that of milling factory. After treatment the pH of well water samples of Khartoum area remained almost the same and ranged from 7.2 to 7.8 (Table, 16).

The pH of treated tap water samples of Khartoum area d ranged from 7.5 to 7.8. The highest pH value of the tap water recorded (7.8) was that of mixed farm and public hospital (Table, 17).

4.3.2.4 Electrical conductivity

The electrical conductivity of well water samples collected from Khartoum area ranged from 15 to 320 micromhos/cm. After treatment process the electrical conductivity of well water samples collected from Khartoum area ranged from 430 to 520 micromhos/cm (Table,16).

The electrical conductivity of treated tap water samples collected from Khartoum area ranged from 180 to 254 micromhos/cm (Table, 17).

4.3.2.5 Total suspended solids

The total soluble solids were not detected in any of the samples examined in Khartoum area (Table, 16 and 17).

4.3.2.6 Odor and taste

Odor and taste were within acceptable range in all water samples of Khartoum area (Table 16 and 17).

4.3.3 **Chemical contaminants:**

4.3.3.1 Anions contaminants:

3.4.1.2.1 Total alkalinity

The total alkalinity of raw well water samples collected from Khartoum area showed a discrepancy and ranged from 180 to 250 mg/l. After treatment process the highest value of total alkalinity was that of treated well water of food factory (250 mg/l), and the lowest value was that of bottled water factory 1 (160 mg/l) as shown in table 12. The treatment of raw well had no effect on total alkalinity.

The treated tap water samples had highest alkalinity value of 295 mg/l in residential house 2 and the lowest value of 150 mg/l of public hospital as shown in Table 18.

3.4.1.2.2 Total hardness

Raw well water samples were varied from hard to very hard and showed values ranged from 75 to 184 mg/l as shown in table 18.

The treatment of raw well water in Khartoum lowered the total hardness considerably and the highest value was that of milling factory (45 mg/l).

The treated tap water samples collected from Khartoum area were considered moderately hard to moderately soft and ranged from 40 to 110 mg/l as shown in table 19.

3.4.1.2.3 Flouride

Flouride was not detected in any of raw well water samples collected from Khartoum area (Table 12). After treatment process flouride concentration in treated well water was zero mg/l for all water samples examined (Table 18).

Flouride concentration of treated tap water samples collected from Khartoum area ranged from zero to 1.0 mg/l (Table 19).

3.4.1.2.4 Nitrate

The nitrate concentration of raw well water samples collected from Khartoum area ranged from 20 to 55 mg/l. The treatment lowered its nitrate content markedly. After treatment process the highest values of nitrate

concentration was that of treated well water of milling and dairy farm (25 mg/l) and the lowest value was that of treated well water of bottled factory 1 (10 mg/l) (Table, 18).

Nitrate concentration of treated tap water samples collected from Khartoum area ranged from 12 to 35 mg/l as shown in table 19.

3.4.1.2.5 Chloride

The chloride concentration in raw well water samples collected from Khartoum area ranged from 165 to 270 mg/l. After treatment process chloride concentration of well water decreased considerably and the concentration ranged from 22 to 55 mg/l (Table, 18).

Chloride concentration in treated tap water samples collected from Khartoum area ranged from 36 to 55 mg/l (Table, 19).

3.4.1.2.6 Sulfate

The sulfate concentration of raw well water samples of Khartoum area ranged from 145 to 250 mg/l. The highest value of sulfate concentration after treatment process was that recorded from well water dairy farm well water (190 mg/l)) and the lowest value recorded was that of milk processing factory milling factory treated well water (100 m/l) as shown in table 18.

Sulfate concentration of treated tap water samples collected from Khartoum area ranged from 88.0 to 106 mg/l (Table, 19).

4.3.3.1.7 Residual chlorine

The residual chlorine in well water samples collected from Khartoum area after treatment ranged from 0.001 to 0.12 mg/l as shown in table 18.

No residual chlorine was detected in treated tap water samples collected from Khartoum area as shown in table 19.

4.3.3..2 Cations contaminants:

4.3.3.2.1 Sodium

The sodium concentration of raw well water samples collected from Khartoum area ranged from 8.4 to 14.2 mg/l. After treatment process sodium concentration ranged from 4.5 to 10.0 mg/l as shown in table 20. this indicated that the treatment of raw well water decreased its sodium content. Sodium concentration of treated tap water samples collected from Khartoum area ranged from 8.4 to 14.0 to 20 mg/l as shown in table 21.

4.3.3.2.2 Potassium

The potassium concentration of raw well water samples collected from Khartoum area ranged from 1.48 to 25 mg/l. After treatment process potassium concentration of raw well water of Khartoum area was not affected and ranged from 1.5 to 22 mg/l as shown in table 20.

Potassium concentration of treated tap water samples collected from Khartoum area ranged from 12 to 28 mg/l as shown in table 21.

4**.3.3.2.5. Iron**

Iron concentration of raw well water samples collected from Khartoum area ranged from 1.02 to 4.02 mg/l. After treatment process the

iron concentration of well water of Khartoum area decreased and ranged from 0.01 to 0.40 mg/l as shown in table 20.

Iron concentrations of treated tap water samples collected from Khartoum area ranged from 0.04 to 0.35 mg/l as shown in table 21.

4..3.3.2.4 Calcium

Calcium concentrations of raw well water samples collected from Khartoum area ranged from 25 to 42 mg/l. After treatment process there were slight decrease in calcium concentrations which ranged from 20 to 42 mg/l as shown in table 20.

Calcium concentrations of treated tap water samples collected from Khartoum area ranged from 12.0 to 40 mg/l as shown in table 21.

4.3.3.2.5 Magnesium

Magnesium concentration of raw well water samples collected from Khartoum area ranged from 6.5 to 8.5 mg/l. After treatment process magnesium concentration of well water fluctuated and ranged from 4.0 to 56.0 mg/l (Table, 20).

Magnesium concentration of treated tap water samples collected from Khartoum area ranged from 58.0 to 100.0 mg/l as shown in table 21.

Table 14: Total bacterial counts and coliform count of raw and treated well water collected from Khartoum area

Location of collected samples	Sample source	Parameter mean value			
		Total count/5ml		**Coliform count /100ml**	
		Raw	**Treated**	**Raw**	**Treated**
Milling factory	Well	018.67	834.00	0.00	0.00
Food factory	Well	048.33	88.00	0.33	0.00
Dairy farm	Well	00.67	824.33	0.00	0.00
Milk processing factory	Well	146.33	685.67	0.00	0.00
Bottled water factory 1	Well	184.33	168.67	0.00	0.00
Bottled water factory 2	Well	157.67	113.00	0.00	0.00

Table 15: Total Bacterial counts and coliform count of treated tap water collected from Khartoum area

Location of collected samples	Sample source	Parameter mean value	
		T. count/5ml	Coliform count/100ml
Mixed animal farm	Tap	00.67	0.00
Public hospital	Tap	309.00	0.00
Private hospital	Tap	116.67	0.00
Residential house1	Tap	02.67	0.00
Residential ouse 2	Tap	387.67	0.00

Table 8: Physical properties of raw and treated well water collected from Khartoum North area

Location of collected samples	Sample source	Parameter mean value											
		Raw						Treated					
		pH	Turbidity NTU	EC micromho	TSS mg/l	TDS mg/l	Odor/taste	pH	Turbidity NTU	EC micromh os/cm	TSS mg/l	TDS mg/l	Odor/taste
Milling factory	Well	7.7	145.0	500	NIL	450	Acceptable	7.5	5.0	190	NIL	100	Acceptable
Food factory	Well	7.8	95.0	450	NIL	650	Acceptable	7.0	26.0	195	NIL	105	Acceptable
Dairy farm	Well	7.5	105.0	300	NIL	325	Acceptable	7.5	5.0	195	NIL	100	Acceptable
Milk processing factory	Well	7.5	105.0	320	NIL	554	Acceptable	7.0	5.0	105	NIL	100	Acceptable
Bottled water factory 1	Well	7.6	85.0	220	NIL	660	Acceptable	6.8	5.5	115	NIL	80	Acceptable
Bottled water factory 2	Well	7.5	65.0	400	NIL	550	Acceptable	7.5	25	125	NIL	85	Acceptable

NTU=Nephlometric turbidity unit; EC= Electrical conductivity; TSS= Total suspended solids; TDS= Total dissolved solids

Table 9: Physical properties of treated tap water collected from Khartoum North area

Location of collected samples	Sample source	P a r a m e t e r mean value					
		pH	**Turbidity NTU**	**EC** micromh os/cm	**TSS mg/l**	**TDS mg/l**	**Odor/taste**
Mixed animal farm	Tap	7.6	15.0	195	NIL	105	Acceptable
Public hospital	Tap	7.5	08.0	205	NIL	105	Acceptable
Private hospital	Tap	7.6	07.6	185	NIL	105	Acceptable
Residential house1	Tap	7.5	36.0	85	NIL	550	Acceptable
Residential house 2	Tap	7.8	44.0	115	NIL	530	Acceptable

NTU=Nephlometric turbidity unit; EC= Electrical conductivity; TSS= Total suspended solids; TDS= Total dissolved solids

Table 16: Physical properties of raw and treated well water collected from Khartoum area

Location Of collected Samples	Sample source	Parameter mean value											
		Raw						**Treated**					
		pH	Turbidity NTU	EC micromh os/cm	TSS mg/l	TDS mg/l	odor/taste	pH	Turbidity NTU	EC mg/l	TSS mg/l	TDS mg/l	Odor/taste
Milling factory	Well	8.0	106	320	NIL	550	Acceptable	7.5	5	430	NIL	260	Acceptable
Food factory	Well	7.8	150	220	NIL	650	Acceptable	7.5	7.0	452	NIL	155	Acceptable
Dairy farm	Well	7.8	185	210	NIL	550	Acceptable	7.2	7.5	520	NIL	260	Acceptable
Milk Processing factory	Well	7.8	106	15	NIL	295 375	Acceptable	7.5	5	520	NIL	106	Acceptable

Bottled water factory 1	Well	7.6	105	14	NIL	585	Acceptable	7.8	5	480	NIL	105	Acceptable
Bottled water factory 2	Well	7.7	105	15	NIL		Acceptable	7.8	5	430	NIL	145	Acceptable

NTU=Nephlometric turbidity unit; EC= Electrical conductivity; TSS= Total suspended solids; TDS= Total dissolved solids

Table 17: Physical properties of treated tap water collected from Khartoum area

Location of collected samples	Sample source	P a r a m e t e r mean value					
		pH	**Turbidity**	**EC micromhos/cm**	**TSS mg/l**	**TDS mg/l**	**Odor/taste**
Mixed animal farm	Tap	7.8	15.0	254	NIL	200	Acceptable
Public hospital	Tap	7.8	8.0	180	NIL	295	Acceptable
Private hospital	Tap	7.7	9.5	185	NIL	285	Acceptable
Residential house1	Tap	7.6	22	190	NIL	295	Acceptable
Residential house 2	Tap	7.5	46	195	NIL	290	Acceptable

NTU=Nephlometric turbidity unit; EC= Electrical conductivity; TSS= Total suspended solids; TDS= Total dissolved solids

Table 10: Chemical anions contaminants in raw and treated well water collected from Khartoum North area

Location of collected samples	Sample Source	Parameters mean value													
		Raw							Treated						
		TA mg/l	TH mg/l	F^- mg/l	NO_3 mg/l	Cl^- mg/l	SO_4 mg/l	RCl mg/l	TA mg/l	TH mg/l	F^- mg/l	NO_2 mg/l	Cl^- mg/l	SO_2 mg/l	RCl mg/l
Milling factory	Well	180	188	1.3	5.2	350	175	0	150	60	0.2	0.0	177	32	0.12
Food factory	Well	185	180	3.0	8.2	150	180	0	140	74	0.3	6.0	142	5.0	0.01
Dairy farm	Well	360	200	2.5	5.0	450	175	0	150	61	0.8	1.2	131	20	0.03
Milk processing factory	Well	340	190	1.2	3.2	185	166	0	150	80	0.6	0.2	125	18.5	0.01
Bottled water factory 1	Well	560	180	3.5	3.0	350	160	0	160	72	0.21	0.0	107	18.5	0.02
Bottled water factory 2	Well	450	185	2.2	3.1	290	170	0	160	72	0.01	0.8	180	17.5	0.01

TA= Total alkalinity;TH= Total hardness F^- = Flouride; $NO_{2=}$ Nitrate; Cl^- = chloride; $SO_{2=}$ Sulfate; RCl= Residual Chlorine

Table 11: Chemical anions contaminants of tap water collected from Khartoum North area

Location of collected samples	Sample source	Parameter mean value						
		TA mg/l	**TH mg/l**	**F^- mg/l**	**NO_3 mg/l**	**Cl^- mg/l**	**SO_4 mg/l**	**RCl mg/l**
Mixed animal farm	Tap	122	85.0	0.0	1.2	42	16.5	0.00
Public hospital	Tap	140	60	0.0	6.0	25	12.5	0.00
Private hospital	Tap	160	66	0.0	4.5	0.7	10.0	0.00
Residential house1	Tap	70	30	0.0	0.12	90	13.0	0.00
Residential house 2	Tap	50	75	0.0	2.4	105	12.5	0.00

TA= Total alkalinity; TH= Total hardness; F^- = Flouride $NO_{2=}$ Nitrate; Cl^-= Chloride; $SO_{2=}$ Sulfate; RCl= Residual Chlorine

Table 18 : Chemical anions contaminants in raw and treated well water collected from Khartoum area

Location of collected samples	Sample source	Parameter mean value													
		Raw							Treated						
		TA mg/l	**TH mg/l**	**F^- mg/l**	**NO_3 mg/l**	**Cl^- mg/l**	**SO_4 mg/l**	**RCl mg/l**	**TA mg/l**	**TH mg/l**	**F^- mg/l**	**NO_3 mg/l**	**Cl^- mg/l**	**SO_4 mg/l**	**RCl mg/l**
Milling factory	Well	245	160	0.00	55	250	150	0.0	165	45	0.0	25	55	100	0.120
Food factory	Well	250	184	0.00	45	250	160	0.0	250	40	0.0	20	45	180	0.001
Dairy farm	Well	250	160	0.00	55	250	145	0.0	155	41	0.0	25	47	190	0.002
Milk processing factory	Well	150	120	0.02	45	165	158	0.0	165	42	0.0	24	35	100	0.030
Bottled water factory 1	Well	190	90	0.00	25	250	250	0.0	160	35	0.0	10	30	155	0.001
Bottled water factory 2	Well	180	75	0.02	20	270	240	0.0	162	25	0.0	15	22	170	0.010

TA= Total alkalinity; TH= Total hardness; F^- = Flouride $NO_{2=}$ Nitrate; Cl^-= Chloride; $SO_{2=}$ Sulfate; RCl= Residual Chlorine

Table 19: Chemical anions contaminants of treated tap water collected from Khartoum area

Location of collected samples	Sample source	Parameter mean value						
		TA mg/l	**TH** mg/l	**F^-** mg/l	**NO_3** mg/l	**Cl^-** mg/l	**SO_4** mg/l	**RCl** mg/l
Mixed animal Farm	Tap	145	45	1.0	35	45	100	0
Public Hospital	Tap	150	110	0.2	32	55	102	0
Private Hospital	Tap	170	40	0.0	21	55	106	0
Residential House1	Tap	180	65	0.1	12	46	98	0
Residential House 2	Tap	295	70	0.2	17	36	88	0

TA= Total alkalinity; TH= Total hardness; F^- = Flouride $NO_{2=}$ Nitrate; Cl^-= Chloride; $SO_{2=}$ Sulfate; RCl= Residual Chlorine

Table 12 : Chemical cations contaminants of raw and treated well water collected from Khartoum North area

Location of collected samples	Sample source	Parameter mean value									
		Raw					Treated				
		Na^{+1} mg/l	K^{+1} mg/l	Fe^{++2} mg/l	Ca^{++2} mg/l	Mg^{++2} mg/l	Na^{+1} mg/l	K^{+1} mg/l	Fe^{++2} mg/l	Ca^{++2} mg/l	Mg^{++2} mg/l
Milling Factory	Well	35.0	15	0.15	70.0	6.6	24.7	5.5	0.00	25.0	5.0
Food Factory	Well	34.5	16	0.13	65.0	5.2	14.7	0.15	0.13	15.0	4.5
Dairy Farm	Well	74.8	14	0.12	70.0	18.5	74.8	0.16	0.120	10.0	20.0
Milk Processing Factory	Well	65.5	14	0.12	75.0	5.6	16.5	1.46	0.001	7.5	15.0
Bottled Water Factory 1	Well	45.5	17	0.16	70.0	7.6	2.5	0.12	0.000	6.5	6.0
Bottled Water Factory 2	Well	44.2	28	0.18	75.2	4.5	25.2	3.0	0.020	5.2	4..0

Table 13: Chemical cations contaminants of treated tap water collected from Khartoum North area

Location of collected samples	Sample source	Parameter mean value				
		Na^{+1} mg/l	K^{+1} mg/l	Fe^{++2} mg/l	Ca^{++2} mg/l	Mg^{++2} mg/l
Mixed animal farm	Tap	18.2	2.19	0.13	24.00	4.48
Public hospital	Tap	18.2	0.39	0.14	45.20	7.78
Private hospital	Tap	16.5	1.56	0.18	22.00	14.58
Residential house1	Tap	12.5	0.29	0.14	41.00	3.9
Residential house 2	Tap	12.4	0.21	0.15	12.10	9.6

Table 20: Chemical cations contaminants of raw and treated well water collected from Khartoum area

Location of collected samples	Sample source	Parameter mean value									
		Raw					Treated				
		Na^{+1} mg/l	K^{+1} mg/l	Fe^{++2} mg/l	Ca^{++2} mg/l	Mg^{++2} mg/l	Na^{+1} mg/l	K^{+1} mg/l	Fe^{++2} mg/l	Ca^{++2} mg/l	Mg^{++2} mg/l
Milling factory	Well	14.00	15.00	4.02	25	7.5	10.0	14.0	0.20	25	04.0
Food factory	Well	13.50	01.48	3.01	30	6.5	8.0	2.5	0.14	20	07.7
Dairy farm	Well	14.20	02.60	1.02	35	6.5	7.1	1.5	0.02	25	14.5
Milk processing factory	Well	8.40	01.90	1.02	40	6.5	6.5	1.8	0.01	42	19.2
Bottled water factory 1	Well	8.50	08.80	1.40	42	6.5	4.3	20	0.20	30	56.0
Bottled water factory 2	Well	8.50	25.00	1.02	30	8.5	4.5	22	0.40	35	40.0

Table 21: Chemical cations contaminants of treated tap water collected from Khartoum area

Location of collected samples	Sample source	Parameter mean value				
		Na^{+1} mg/l	K^{+1} mg/l	Fe^{++2} mg/l	Ca^{++2} mg/l	Mg^{++} mg/l
Mixed animal farm	Tap	20	12	0.30	22	100
Public hospital	Tap	21	12	0.12	12	105
Private hospital	Tap	18	28	0.04	24	103
Residential house1	Tap	14	22	0.35	40	100
Residential house 2	Tap	15	12	0.30	35	58.0

Chapter Five

5. Discussion

The results of microbiological and chemical examinations of drinking water samples collected from Khartoum North and Khartoum area are presented in tables 6 to 21.

Microbiological examination of water in this study showed that two raw well water samples of milling and food factory collected from Khartoum North area were polluted by coliform bacteria as the count 0.33 colony/100ml exceed the count allowed by WHO (1993) and SSMO (2002). After treatment the coliform count of milling factory increased from 0.33 to 1.0 and that of dairy farm became more polluted and count increased from zero to 0.67 colony/ml. The potential health effects from ingestion of this water are gastrointestinal illness such as diarrhea, vomiting and cramps (USEPA, 1996).

The total bacterial count of the raw well water samples collected from Khartoum North (70.67 to 480.33colony/5 ml) are not acceptable by WHO (1993) and SSMO (2002), while Khartoum public water corporation (KPWC) (Almugran laboratory) allow total count less than 1000 colony/5ml.

The total count observed after treatment of raw well water of Khartoum North area were 824.0 and 834.0 colony/5ml in milling factory and dairy farm indicates inefficiency of treatment process. The increase count indicates the bacterial contamination, possibly by potentially harmful bacteria.

In the treated tap water samples collected from Khartoum North no coliforms were detected and the total bacterial count reported in public hospital and residential house2 were 309.0 and 387.67 colony/5ml respectively violated the range of the WHO (1993) and EPA (1996) standards. On the other hand it is accepted by Khartoum Public water Corporation (KPWC) and Almugarn Laboratory. Elroufaai (2000) reported that in Sudan the incidence of fecal streptococci contamination was variable, it is highest during winter (November–December) in village around Khartoum while, in city there were no fecal streptococci contamination.

The highest total bacterial count mean value of raw well water of Khartoum area reported were 184.33 and 157.67/5ml. After treatment total count increased in all location which reflects inadequacy of treatment process. The total bacterial count of treated well water also does not cope with the WHO (1993) and SSMO (2002) standards and it is not satisfactory for bottled water factories. However, the coliform count reported was zero before and after treatment process.

In the treated tap water samples collected from Khartoum area no coliform count were reported similar to results obtained by Ibrahim (1999) which were within the acceptable level of WHO (1993) and USEPA (1996). The total bacterial count reported for residential house and public hospital were 387.67 and 309/5ml respectively which exceeds the WHO (1993) and SSMO (2002) standards but within the acceptable level of Sudan Ministry of Health (2002).

Physical and chemical contaminants

The results of physical and chemical examinations of drinking water samples collected from Khartoum North and Khartoum area are presented in tables 6 to 17.

It was observed that the turbidity mean value of raw well water collected from Khartoum North and Khartoum area (65.0 to 185 mg/l) exceeds the admissible level of WHO (1993) and SSMO (2002), after treatment there is an obvious decrease in turbidity level which meets the WHO (1993) standards (5.0 NTU) and pointed out the efficiency of treatment processes.

The change in turbidity values after treatment shows the effectiveness of treatment processes in the milling factory, dairy farm, milk processing and bottled water factory which meets the WHO 1993 Standards (5 NTU), on the other hand the turbidity readings for Bottled water factory2 and Food factory in Khartoum North area were 25 and 26 NTU respectively exceed the admissible level of WHO (1993).

The turbidity mean value of treated tap water samples collected from Khartoum North area shows 44.0 for residential house 2 and 36. 0 for residential house 1 and 46.0 mg/l for residential house 2 in Khartoum area which exceeds 5.0 NTU of WHO 1993 standards.

The pH mean value of raw well water collected from Khartoum North and Khartoum area were ranged from 7.5 to 7.8. after treatment there are slight decrease in the pH (6.8 to 7.5) and within the acceptable level of WHO(1993) and SSMO (2002). While the pH of treated tap water (7.5 to 7.8) collected from all locations in Khartoum North and Khartoum area meets the admissible level of WHO (1993) and USEPA (1999).

The Electrical conductivity readings ranged from 220 to 500 micromhos/cm for raw well water collected from Khartoum North area and 14 to 320 micromhos/cm for raw well water samples collected from Khartoum area. After treatment process E.C reported for well water of Khartoum North 105 to 195 micromhos/cm and for well water of Khartoum area 432 to 520 micromhos/cm.

Electrical conductivity readings for treated tap water of Khartoum North (85 to 205 micromhos/cm) and of Khartoum area (180 to 254 micromhos/cm), all readings meets the admissible level of WHO (1993) standandars (<1000 micromhos/cm).

Total dissolved solids in well water samples collected from Khartoum North area showed a significant decrease after treatment process. Total dissolved solids (100mg/l) reported for milling factory, dairy factory and milk processing factory and 105 mg/l for food factory, 115 mg/l for bottled factory1 and 125 mg/l for bottled factory 2 and all within the acceptable level of WHO (1993) and USEPA (1999) standards (< 500 mg/l).

Total dissolved solids in treated tap water collected from Khartoum North area were within the acceptable level except samples collected from residential house 1 and 2 550 and 530 mg/l respectively, which exceeds the permissible level of USEPA (1999) and WHO (1993).

The TDS of raw well water collected from Khartoum area ranged from 295 to 650 mg/l, after treatment process it decreased and ranged 105 to 260 mg/l, which are within acceptable range. The TDS in treated tap water collected from Khartoum area showed an agreeable values of WHO 1993 (< 500 mg/l).

No total suspended solids were detected in all sample of raw and treated well water and treated tap water samples collected from Khartoum North and Khartoum area.

Odor and taste were estimated by direct smelling and tasting and were found acceptable for all samples collected from Khartoum North and Khartoum area and coped with WHO (1993) standards.

Chemical anions:

Total alkalinity of raw well water, treated well water and treated tap water of Khartoum North and Khartoum area showed values (Table 10, 11, 12 and 13) within the acceptable level of maximum (500 mg/l) WHO (1993) and USEPA (1999).

Total hardness of the raw well water samples collected from Khartoum North ranged from (180 to 200 mg/l) and considered very hard as WHO (1993) standards (>180 mg/l). Hard water does not pose a health risk, but can cause aesthetic problems such as formation of a "scale" or precipitate on piping and fixtures causing water pressures and interior diameter of piping to decrease, difficulty in getting soaps and detergents to foam and formation of insoluble precipitates on clothing and decreases efficiency of electric water heaters (Herman and Jennings, 1996).

Total hardness of Khartoum area raw well water ranged from (75 to 184 mg/l) and varied from soft to moderate. There are a considerable decrease in hardness after treatment of raw well water and water hardness changed to moderately soft according to WHO (1993) standards (20 – 60 mg/l) as in bottled water factory 1 and 2.

Total hardness in the treated tap water samples collected from Khartoum North ranged from (30 to 85.0 mg/l) and of Khartoum area ranged from (40 to 110 mg/l) except water samples of private hospital and mixed animal farm and Public hospital in Khartoum area samples which were moderately hard (20 - 60 mg/l) according to WHO (1993) standards.

Fluoride concentration in raw well water samples collected from Khartoum North area ranged 1.2 to 3.5 mg/l after treatment fluoride concentration decreased (0.01 to 0.8 mg/l) as indication of efficiency of treatment process. No fluoride was detected in treated tap water collected from Khartoum North area nor in Khartoum area raw and treated well water samples. In treated tap water collected from Khartoum area fluoride concentration ranged from (0.0 to 1.0 mg/l) and within the WHO (1993) acceptable level (0.7 to 1.2 mg/l). Additions of fluoride require close control of fluoride concentrations to roughly 1.0 mg/l as higher levels cause mottling of the teeth (Greenberg *et al*. 1998). Opponents have long argued that fluoridation violates individual rights, certain religious beliefs that ban medications, and does not prevent tooth decay (Fundingsland, and Lundstrom, 1988).

Nitrate concentrations of raw well water collected from Khartoum North and Khartoum area ranged from (3.0 to 8.2 mg/l) and (20 to 55 mg/l) respectively. However, after treatments the nitrate concentration of well water of Khartoum North and Khartoum area ranged from (0.0 to 6.0 mg/l) and (10 to 25 mg/l) respectively and were within the WHO (1993) and SSMO (2002) standards. Significant sources of nitrate are chemical fertilizers from cultivated land, drainage from livestock feed lots as well as

some industrial waters (Greenberg *et al*., 1998). This may explain high level of nitrate in raw well water collected from Khartoum area.

All samples of treated tap water collected from Khartoum North ranged from (0.12–6.0 mg/l) and Khartoum area ranged from (12–35 mg/l) showed nitrate concentration within the acceptable level of WHO 1993 standards (45 mg/l).

High nitrate levels in water can cause methemoglobinemia or blue baby syndrome, a condition found especially in infants less than six months. Although there is no enforceable drinking water standard for livestock, animals are not allowed to drink water with more than 100 mg/l NO_3-N. This is especially true of young animals. They are affected by nitrates the same way as human babies. Older animals may tolerate higher levels (Self, 1998).

Chloride concentration of raw well water samples collected from Khartoum North area are very high in four water sources such as milling factory, dairy farm, bottled water factory 1 and 2 which showed chloride concentration of 350, 450, 350 and 290 respectively. The chloride concentration 250 to 270 mg/l of raw well water of Khartoum area except that of milk processing factory (165.0 mg/l) also exceeds the WHO (1993) 250 mg/l. After treatment process chloride concentrations of both Khartoum North (107–180 mg/l) and Khartoum area (22–55 mg/l) decreased and within acceptable level of WHO (1993) standards.

The chemical analysis of chloride concentration in treated tap water collected from Khartoum North (0.7 to 105 mg/l) and Khartoum area (36 to 55mg/l) showed acceptable level of WHO (1993) and USEPA (1996) (250 mg/l).

Sulfate concentration in raw well water collected from Khartoum North area ranged from 160 to 180 mg/l and showed concentration lower than safe concentration of WHO (1993) standards (250mg/l). After treatment process the well water factories ranged from 50 to 32.0 g/l. This showed treatment process almost removed the sulfate from well water or reduced it to very low concentration. The raw well water of Khartoum area showed sulfate concentration of 145–250 mg/. After treatment the sulfate concentration decreased to 100–190 mg/l. This also showed treatment process decrease the sulfate concentration to acceptable level.

Sulfate concentration of treated tap water of Khartoum North and Khartoum area were found below the threshold, the highest value was for mixed animal farm (16.5 mg/l) and in the two residential houses 12.5 mg/l. Sulfate content in excess of 250 to 500 mg/l may give water a bitter taste and have a laxative effect on individuals not adapted to the water (Stewart *et al.* 1998).

Residual chlorine as disinfectant by products was not detected in raw well water collected from Khartoum North and Khartoum area, however, the residual chlorine concentration in treated well water collected from Khartoum North area (0.01–0.12 mg/l) showed level below the limit (0.2 to 0.5 mg/l) acceptable by WHO (1993). Treated well water samples collected from Khartoum area showed residual chlorine below the threshold 0.001 to 0.120 mg/l

Disinfection of water which has turbidity greater than 5 NTU is ineffective (WHO, 1993). Treated well water samples collected from Khartoum area showed residual chlorine below the threshold 0.001 to 0.120 mg/l.

In treated tap water collected from Khartoum North and Khartoum area the residual chlorine concentrations was zero also this is attirbuted to high turbidity level of treated tap water which showed level greater than 5.0 NTU. This because the efficiency of any disinfection process depends upon the water being treated to a high degree of purity, as disinfectants will be neutralized to a greater or lesser extent by organic matter and readily oxidizable compounds in water (WHO, 1993). In Sudan Karar (2002) observed that residual chlorine concentration were found as 4.0, 3.2 and 3.02 mg/l in Almogran, Buri and Beit Alamal respectively.

Sodium concentrations in raw well water collected from Khartoum North area (34 to 74 mg/l) was above the threshold of WHO (1993) (20 mg/l). in all raw well water samples and the highest value was reported for the dairy farm 74.0 mg/l and 65.0 mg/l milk processing factory. After treatment there were observable decrease in sodium concentration (2.5 – 74.8 mg/l) but still some sources showed level above the recommended level by WHO 1993 standards (< 20 mg/l).

Sodium concentration in Khartoum area in raw well water before and after treatment (8.5 to 14.0 mg/l) and (4.3 to 10.0 mg/l) respectively was below threshold and meets WHO (1993) standards (< 20 mg/l).

In treated tap water of Khartoum North and Khartoum area sodium concentration (12.4 to 18.2mg/l) and (14 to 20mg/l) meets the WHO (1993) standards in all locations.

A survey by EPA in the mid-1980s showed that elevated levels of sodium in drinking water did not cause high blood pressure or heart disease, rather only that sodium should be avoided by those people who already had such medical conditions.

Potassium concentrations in raw well and treated water samples in all locations of Khartoum North (14 to 28 mg/l) and (0.12 to 5.5 mg/l) and Khartoum area (1.48 to 25.0 mg/l) and 1.5 to 22.0 mg/l) were within the acceptable level of WHO (1993) and SSMO (2002) the highest value recorded was that for bottled factory1 (22 mg/l) in Khartoum area. The potassium concentration in tap water collected from Khartoum North area ranged between 0.21–2.19 mg/l while that of Khartoum area ranged between 12–28 mg/l and all within the acceptable level of WHO (1993) standards.

Iron concentrations in raw (0.12–0.18 mg/l), treated well water (0.0–0.13 mg/l) and treated tap water (0.13–0.18 mg/l)collected from Khartoum North area appear to be within the acceptable level of international standards of < 0.3 mg/l WHO (1993) and similar results were also reported by Karar (2002).

Iron concentration of raw well water (1.02–4.02 mg/l) collected from Khartoum area showed a high values compared to international standards (WHO 1993; USEPA (1996). After treatment there were a tremendous decrease (0.01 to 0.4 mg/l) which attributed to the effectiveness of treatment plants in iron concentration control.

Iron concentration of treated tap water (0.04–0.35 mg/l) collected from Khartoum area showed an acceptable limits that agree with international standards (WHO, 1993; SSMO, 2002; EPA, 1996) (<0.3 mg/l). However Iron is not hazardous to health, but it is considered a secondary or aesthetic contaminant. Essential for good health, iron helps transport oxygen in the blood (Environmental Health Fact sheet, 1999).

Calcium concentration in raw (65- 75.2 mg/l) and treated well water (5.2 – 25 mg/l) and treated tap water (12.1– 45.2 mg/l) samples collected

from Khartoum North showed allowable values (Table 14,15 and 16) and all below the threshold value for calcium ion concentration as indicated by WHO (1993) (100 – 300mg/l). The calcium concentration in raw well water (25 – 42.6 mg/l), treated well water (20 – 42 mg/l) and treated tap water collected from Khartoum area also showed allowable value of calcium ions concentration indicated by WHO (1993) 100 – 300 mg/l. Simillar results were also obtained by Karar (2002) in Khartoum state.

Magnesium concentration in well water (45- 18.5 mg/l), treated well water (4–20 mg/l) and treated tap water (3.9–14.58 mg/l) collected in Khartoum North area showed acceptable values and all below the threshold value of magnesium ions concentration indicated by WHO (1993) (50 -150 mg/l).

The water samples collected from raw well water (6.5–8.5 mg/l), treated well water (4-56 mg/l) and treated tap water (58–105 mg/l) in the Khartoum area showed allowable values and all below the standards concentration (50–150 mg/l) of WHO (1993).

Finally I want to state that there were no published work in Sudan specifically on private well water quality issues and it the first comprehensive study.

Chapter Five

Conclusions and Recommendations

5.1. Conclusions

From the results and the findings of the present investigation, it can be concluded:

1. Raw well water is not completely safe for human and animal consumption because:
    a. Raw well water was contaminated by coliform bacteria in some location.
    b. The total bacterial count of raw well water are not acceptable in some locations in Khartoum and Khartoum North areas.
    c. Turbidity exceeds the admissible level of WHO (1993).
    d. Raw well water was very hard in some locations and chloride and sodium concentration were above threshold value (WHO, 1993). However, the pH, EC, total dissolved solids total alkalinity, odor and taste and concentration of fluoride, nitrate, sulfate and potassium were within acceptable level (WHO, 1993).
2. Treatment processes improved the quality of raw well water as the treatment process:
    a. Decreased turbidity of raw well water and sodium concentration to acceptable level.
    b. Decrease the total hardness of raw well water from hard to moderately soft.

c. Decreased the concentrations of fluoride, nitrate, chloride, sulfate, iron and calcium. This indicating the efficiency of treatment process.

3. Treatment process increased total bacterial count coliform count of well water in some locations in Khartoum North area.

4. This indicating bacterial contamination may occur during treatment process.

5. Treated well water could be considered safe for consumption because:

   a. Coliform bacteria were not detected.

   b. The turbidity of treated well water collected from Khartoum and Khartoum North areas meet the WHO (1993) standards.

   c. The total dissolved solids, total suspended solids, pH, EC, total alkalinity, odor and taste are acceptable (WHO, 1993).

   d. The concentration of fluoride, chloride, sulfate, nitrate, sodium, potassium, iron, calcium and magnesium are within acceptable concentrations.

   e. The chlorine residue detected in treated well water meets the admissible level of WHO (1993). However, the total bacterial count was higher than acceptable level (WHO, 1993) in some locations but within acceptable count SSMO and KPWC.

6. Treated tap water is reasonably safe for human and animal consumption and food processing because:

a. Coliform bacteria were not isolated from any water sample collected from Khartoum and Khartoum North.

b. The total dissolved solids, pH, EC, total alkalinity, odor and taste are within the acceptable level (WHO, 1993).

c. The concentration of fluoride, nitrate, chloride, sulfate, sodium, potassium, calcium and magnesium meet the WHO (1993) standards in all locations sampled. Also no residual chlorine was detected.

d. However, the total bacterial count was above the acceptable counts (WHO, 1993). In some location, but within acceptable count of SSMO and KPWC 2002. Also turbidity of treated tap water collected during this study exceed the 5 NTU standards of WHO (1993).

5.2. Recommendations:

From the findings of this study:

1. Raw well water is recommended to be treated to improve it's quality.
2. Further microbiological investigations should be carried out to find the source of bacterial contamination of well water during treatment process.
3. Further microbiological studies should be carried to explain the high total bacterial count of tap water.
4. The high turbidity of tap water observed (more than 5 NTU) may be one of the caused of high total bacterial count, so it is recommended to control the turbidity of tap water.
5. The microbiological, physical and chemical examinations of water.

Sample collected from Khartoum and Khartoum North areas showed that more efforts are needed to be done to improve the water quality to meet the international and WHO standards.

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