CHAPTER ONE

INTRODUCTION

Water is essential to sustain life, and a satisfactory every effort should be made to achieve a drinking-water quality as safe as practicable, (WHO, 2008). Safe drinking-water is required for all usual domestic purposes, including drinking, food preparation and personal hygiene (WHO, 2011). Access to safe drinking-water is essential to health, a basic human right and a componentofeffective policy for health protection .Approximately 1.1 billion people are living without access to 'improved' water sources(WHO/UNICEF,2005).The world community has acknowledged the importance of the provision of safe drinking water for all (WHO, 2004). In Sudan the rural population constitutes about 80% of the totalpopulation, most of the year these people use raw water directly from source such as traditional surface well, deep bores, rivers, intermittent rainyseasons(Khours)naturarainponds,andartificialrainwatercatchment(Hafir s)(AbdelMagided ,1984). Groundwater is usually more suitable as an abstraction source than surface water, since it's more likely to be free from suspended solids, bacteria and other pathogens (Gray, 1994). Forrest(1956) reported that the cute shortages in both surface and underground waters in many localities in the world, careless pollution or contamination of our streams, lake and underground sources has greatly impaired the quality of the available water, its therefore of importance for our future that good conservation and sanitary measures be practiced to insure enough water supply. There is many sources of ground and surface water pollution, many practices with domestic waste water and with livestock manure may lead to contamination of ground water, septic tanks, cesspools, latrines and other

onsite system are widely used for waste water storage and treatment, the water percolating from these facilities contains viruses, bacteria and parasites may contaminate ground water supplies (WHO, 1997). Sources of surface water pollution surveys pathogen occurrence in the sewage system of urbanized area show that pathogen presence in the sewage and sewage effluents in the rule rather than the exception .Treatment of sewage by sedimentation and activated sludge, storm water discharges are a major cause of rapid deterioration in surface water quality ,storms events bring an elevation of turbidity suspended solids ,organic matter and fecal contamination into the drainage basin ,caused by urban and agricultural run-off, discharges from storm water sewers and re-suspension of sediment ,wild animals are another source of fecal contamination. In general mammals and birds (water fall) may shed human pathogens (WHO, 1998).Total Coli form and thermo tolerant (fecal)coli form indicator tests are common public health tests of the safety of water and wastewaterwhich might be contaminated with sewage or fecal material. Enumeration of heterotrophic counts is commonly used as indicator of overall microbiological quality (APHA, 1998).An effective treatment process can remove pathogens that enter the supply system through raw water abstraction. The simplest and most important method, which is also common in developing economies, is chlorine disinfection (Gray, 1994). For more than a century the presence of coliform bacteria in drinking and recreational waters has been taken as an indication of fecal contamination, and thus of a health hazard. Historically, water has played a significant role in the transmission of human disease. Typhoid fever, cholera, infectious hepatitis, bacillary and amoebic dysenteries and many varieties of gastrointestinal disease can all be transmitted by water (Rompre, 2002). Drinking water

microbiological quality is primarily determined by using "indicator organisms", whose presence indicates fecal contamination. The presence of the indicators is often a key in assessing potential public health risks due to pathogens and is used in drinking water quality regulations and guidelines in many countries (Gauthier and Archibald, 2001). The quality of drinking water may be controlled through a combination of protection of water sources control of treatment processes and management of the distribution and handling of the water. Guide lines must be appropriate for national regional and local circumstances which require adaptation to environmental social economic and cultural circumstances and priority setting (WHO, 1997).

MAIN OBJECTIVES;

1.To assessthe Bacteriological quality of potable drinking water supply of Khartoum state.

2. To evaluate the efficiency of water purification project plants for disinfection of water.

CHAPTER TWO

LITERATURE REVIEW

2.1The importanceofwater

The importance of water, sanitation and hygiene for health and development has been reflected in the outcomes of a series of international policy forums. Most recently, the UN General Assembly declared the period from 2005to2015 as the International Decade for Action, "Water for Life (WHO, 2008). Potable water supports public health and ensures economic growth. Water of poor quality can cause social and economic damages through water-related epidemics such as cholera which in turn increases medical treatmentcosts. (Pritchard, 2007).

2.2Water production

This rising demand for drinking water entailed huge challenges for Khartoum governmental water supply system. Two main sources of drinking water exist for Khartoum state, which has arid desert climate groundwater and river water from the Nile. Groundwater is recharged by rainwater to a small extent, and by the Nile to a greater extent (Njiru/Alba, 2004). Accordingly, drinking water in Khartoum state is produced by groundwater wells of varying depth andby water treatment plants, which extract river water from the Nile.The first plants in KhartoumBurri (1924) and Betelmal (1927) were built during the British administration. Three other plantsfollowed Old Bahri (1954), which was extended to New Bahri in 1979, Moghran plant (1964), and a small plant to supply Tuti Island (1984).Four new plants Soba, Gebel Aulia, ShamalBahri, and ElManara were launched in 2009 and 2010(Figure1, 2).
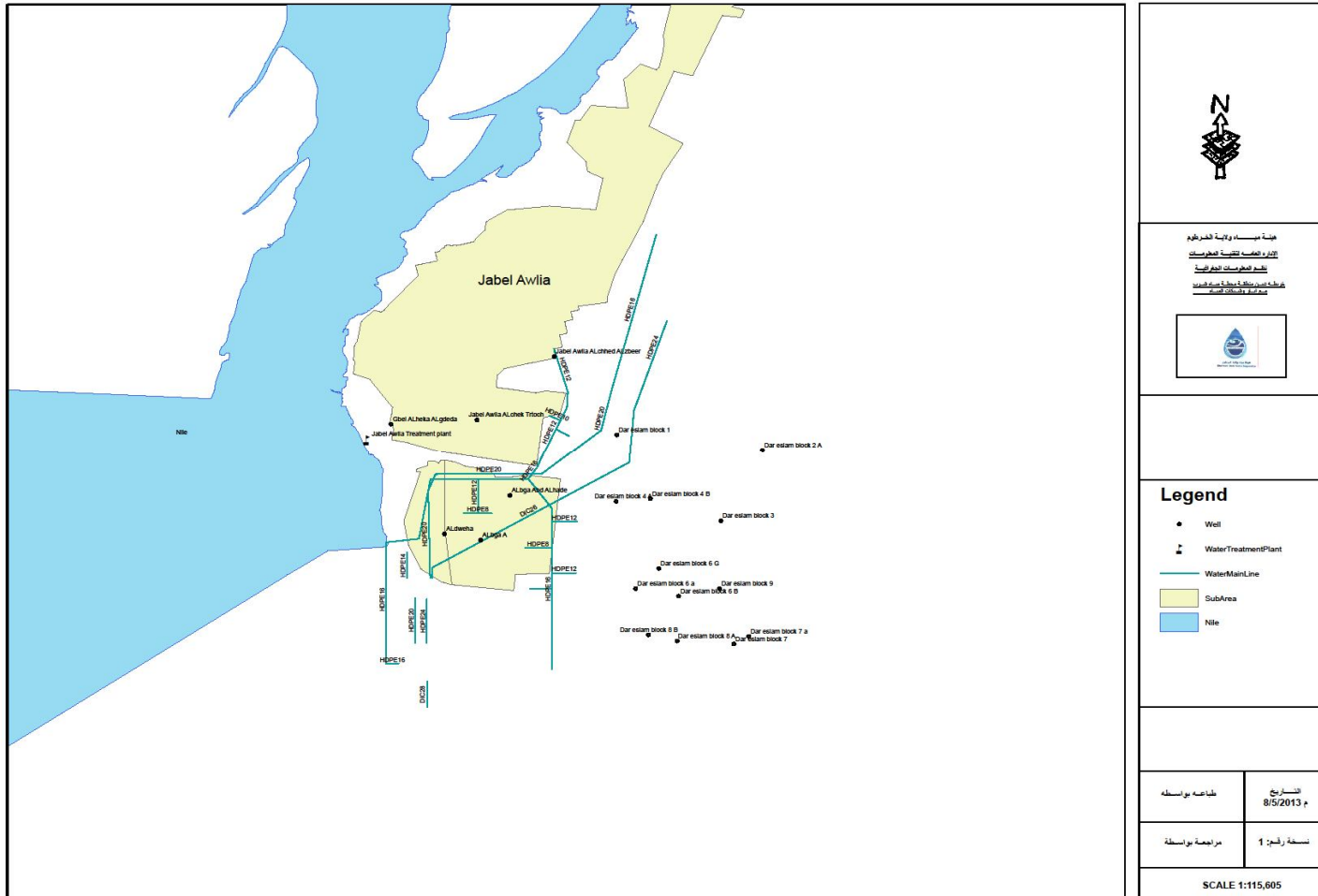
Figure1:
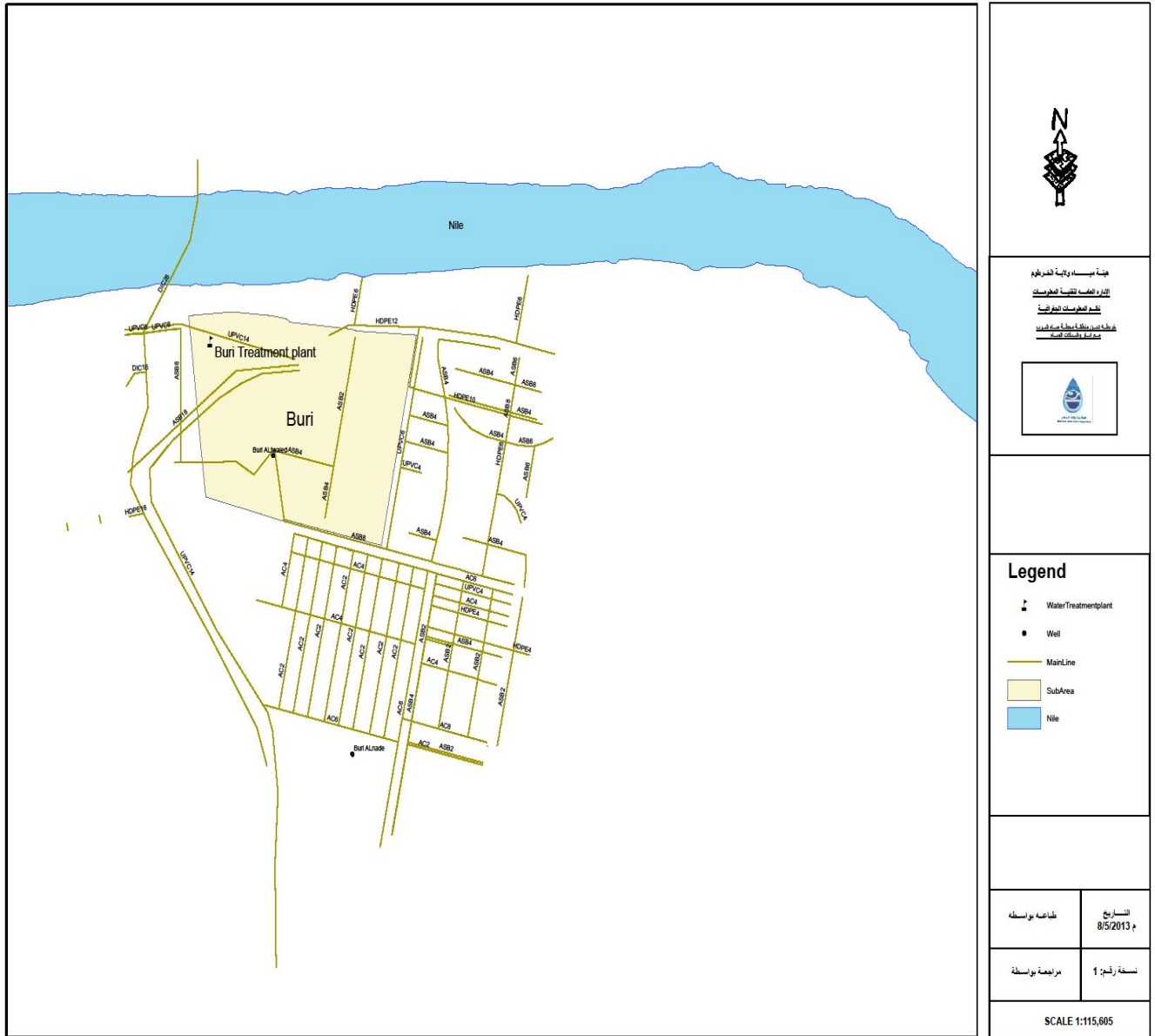
Source: Khartoum State Water Corp (2013)

Management of geographic systems

http://www.kswc.gov.sd/

Buri Treatment plant

Figure2:

JabelAwlia Treatment plant

2.3The BasicsofIndicator Organisms

There exist two main methods to identify microbial contaminated water sources. The first is totest directly for pathogens. Direct testing means that many individual tests have to be run, as eachscreen test for only one unique type of pathogen. Although a more accurate method, exhaustivetesting for pathogens in drinking water can be a cumbersome process involving complicated, timeconsuming and often, expensive procedure, as there are a high number of pathogens that havebeen identified as harmful (Gerba, 2000).

2.4 Microbial indicator

The WHO (2011) recognizes*E. coli* as the indicator of choice for fecal contamination, although *thermotolerantcoliforms* can be used as an alternative (Table1). *Thermotolerant coliforms* are less specific indicators, as strains can grow in the environment and may not be of fecal origin. Although *E. coli* is useful, it has limitations. Enteric viruses and protozoa are more resistant to disinfection; consequently, the absence of cultural*E. coli* will not necessarily indicate freedom from these organisms. Under certain circumstances, the inclusion of more resistant indicators, such as bacteriophages or bacterial spores, should be considered (WHO, 2011).

2.5CurrentIndicatorOrganisms
2.5.1*Total Coliforms*

The coliform group, consisting of gram negative, non-spore forming, and rod shaped bacteria, has traditionally been trusted as the most reliable indicator for drinking water in industrialized nations. Coliforms also are able to ferment lactose within 24-28 hours when incubated at 35°C, a featurethat is helpful in identifying them among other bacteria. Coliforms are also the broadest

categoryof organisms used as an indicator, meaning that a variety of species are used to identify thePotentialpresence of contamination. Often the presence of total coliforms simply indicates thatfurther, more specific testing is required. The species included in the coliform group are not limited to, *Escherichia, Citrobacter, Enterobacter, Klenseilla, Enterobacter cloacae* and*Citrobacterfreundii*(Gerba, 2000).

2.5.2Thermotolerant Coliforms

Thermotolerant coliforms are a subset of the total coliform group. The coliform speciesconsidered part of this subset are only those that have the ability to ferment lactose at atemperature of 44.5° C. Often the term "thermotolerant" is used interchangeably with "fecal,"incorrectly combining temperature and origin classifications. (Gerba, 2000).

2.5.3Fecal Coliforms

Fecal coliforms are a more defined subset within the *thermotolerant coliforms* group. Many ofthese organisms are physiologically similar to their parent set, however their origin is known to bethe gut of a human or other warm-blooded animal species.(Gerba, 2000).

2.5.4Escherichia coli

Commonly known as *E. coli,* is a single species subcategory of fecal coliforms.There are many strains of *E. coli*, only a small fraction of which cause disease. Most commonly itis strain O157:H7 that is to blame for severe cases of breaches in public health (Washington StateDepartment of Health, 2011). However, the presence of any strain of *E. coli* is likely indicative offecal contamination of the water source and further testing is required.

Table 1: Guideline values for verification of microbial quality

Water class Indicator species Guideline value

Water class	Indicator species	Guideline value
All water directly intended for drinking	*E. coli* or *thermotolerant coliform bacteria*	Must not be detectable in any 100-ml sample
Treated water entering the distribution system	*E. coli* or *thermotolerant coliform bacteria*	Must not be detectable in any 100-ml sample
Treated water in the distribution system	*E. coli* or *thermotolerant coliform bacteria*	Must not be detectable in any 100-ml sample

Source: WHO (2006).

2.6The importance of water quality

Safe drinking water is essential for human survival, yet it is unavailable to over 1 billion of theworld's population living in poverty (World Bank, 2009). Almost 2 million people every year (themajority of whom are children) died from water related diseases including diarrhea, dengue feverand typhoid, among others. Diarrhea remains in the third leading cause of death among childrenfewer than five.Globally 1.1 billion people rely on unsafe drinking water sources from lakes, rivers, and open wells (WHO/UNICEF, 2000).

2.7Water and infectious diseases

Water is essential element for living. Ironically humans with their activities keep degrading its quality and quantity. Unsafe water inadequate quantities of water poor sanitation and hygiene are leading to infectious diseases and children are the most group to be infected. Globally every year there are more than 1.5 million children within the age of five and below are died mostly because of diarrhea(UNICEF, 2006). Infectious disease is one that can be transmitted from one to another and caused by microorganism such as bacteria and viruses. These

microorganism are using environmental e.g. water and air as their transportation to be transmit from host to the new victims (Caincross and Feachem, 1993).

Table2: Bradley classification system for water-related diseases

Category	Example	Intervention
Water-borne	Diarrheal disease, cholera, dysentery, typhoid, infectious Hepatitis	Improve drinking-water quality,prevent casual use of unprotected sources
Water-washed	Diarrheal disease, cholera, dysentery, trachoma, scabies, skin and eye infections, ARI(acute respiratoryinfections)	Increase water quantity used Improve Hygiene
Water-based	Schistosomiasis,andguinea Worm.	Reduce need for contact with contaminated water, reduce surface water contamination
Water-related (insect vector)	Malaria, onchocerciasis, dengue fever, Gambian sleeping sickness.	Improve surface water management, destroy insect breeding sites, use mosquito netting

**2.8**Pathogens and Water Contamination

Water contamination can originate from a variety of sources, including industrial or agriculturalrunoff, and poorly treated, or untreated, human and animal waste. In developing countries the most common of contamination ismicrobiologica11, which comes primarily from human or animal feces mixing with drinkingwatersources during transport or at the point of use. More specifically, microbial contamination refersto the introduction of one of any number of

harmful bacteria viruses or protozoa collectivelyknown as pathogens, into a water source given the diverse nature of pathogens, it is not surprising that they behave differently when interacting with a host. While all pathogens have the ability to negatively impact the health of their host, some, such has *Legionella* and *Klebsiella,* do only when the immune system of the host is already vulnerable, as is the often case with children, the elderly and other immune compromised populations. Alternatively, some microbes are harmful to all members of a population, even when present at extremely low levels, as is the case with *E. coli* and *Salmonella*(WHO, 1996).

2.8.1 Fecal-oral transmitted diseases

Pathogenic microorganisms were leaving the host (human or animals) via fecesand then using environment as their pathway to enter the new victims through ingestion (Rottierand Ince, 2003). Figure 3 below known as the F-Diagram demonstrates the various ways that pathogens of fecalorigin can travel to a new host.

Figure 3 F-Diagram
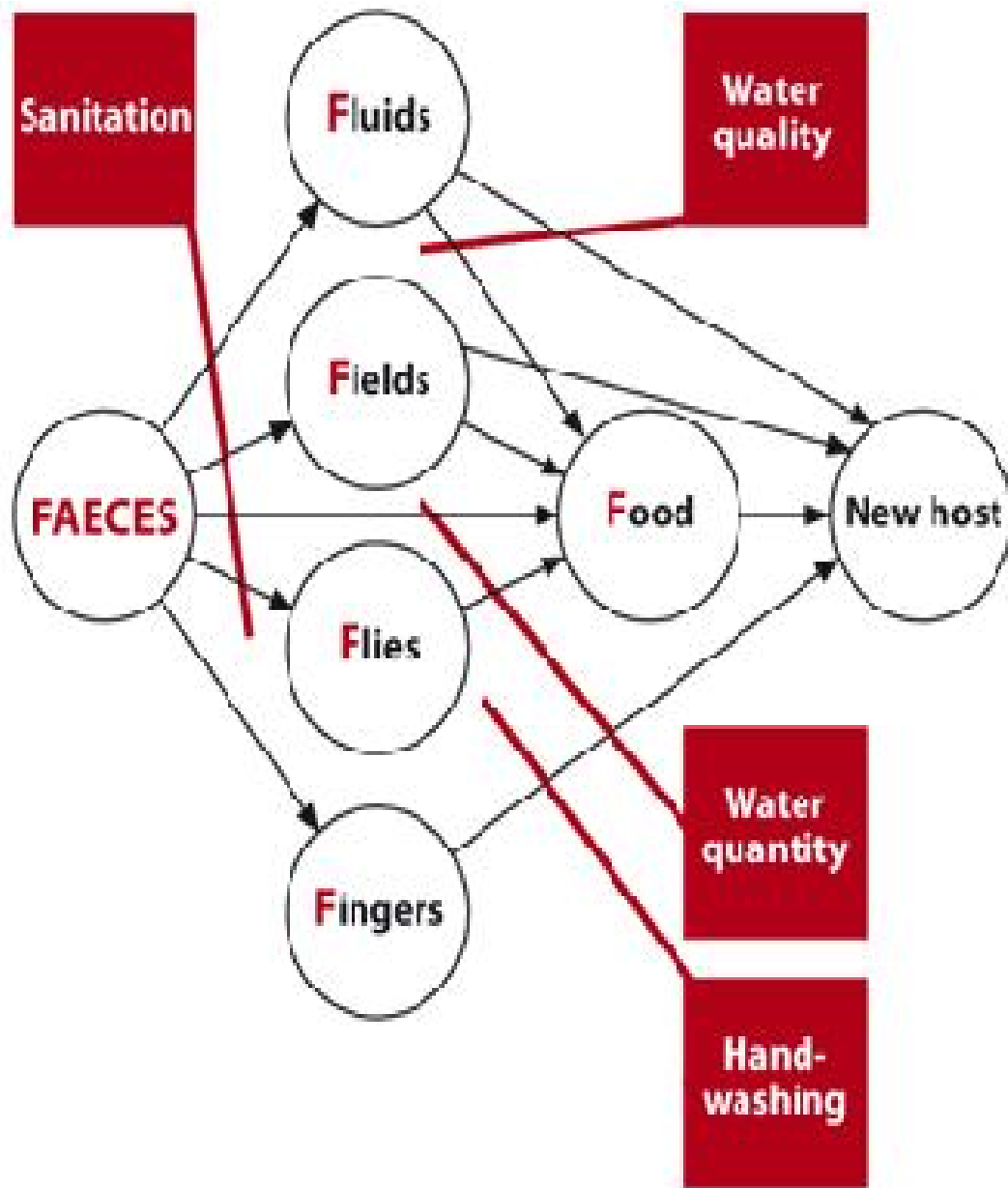
(New Internationalist Magazine, 2011)

Table 3:Fecal-oral pathogens in developing countries

Name of microorganism	Major diseases	Major reservoirs and primary sources
Salmonella typhy	Typhoid fever	Human feces
Salmonella paratyphy	Para Typhoid fever	Human feces
Shigellaspp	Bacillary dysentery	Human feces
EnteropathogenicE. coli	Gastroenteritis	Zooplankton
Yersinia enterocolitica	Gastroenteritis	Human feces
Camplyobacterjejuni	Gastroenteritis	Human & animal feces
Lepstopiraspp	Lepstospirosis	Human & animal feces Human and animal urine

[Source: Caincross and Feachem, 1993]

2.9Disinfection

Maintenance of high pressures in the mains and prevention of cross-connections
Are crucial measures for ingress prevention. Maintaining a disinfectant residual
Aimed at further ensuring the microbiological quality of water in the distribution
System by protecting against microbial contamination and preventing regrowth(Trussell,1999).

2.9.1Chlorine

Chlorine is an effective disinfectant against viruses and bacteria, but to a lesser extentagainst protozoa. Payment (1999) demonstrated that disinfectant concentrations as used in distribution systems had only a limited effect onpathogens. Free chlorine concentrations up to 0.3 mg/liter must be maintained toprevent regrowth and formation of biofilms (Geldreich*et al.* 1972; Speh*et*

*al.*1976). This approach has the following limitations   Chlorine is a highly reactive compound, which forms undesirable sideproducts for which maximum values are defined in legislatione.g., 200 μg/liter for chloroform, 100 μg/liter for bromoformand60 μg/liter forbromodichloromethane,recommended by WHO (1996)which is 100 μg/liter in Europe (European Union1998). Low concentrations of chlorine affect the taste and odour of drinkingwater,causing consumers to complain or to use alternative sources(Burttschell*et al.* 1959).The chlorine residual rapidly declines in the distribution system.Usually after about a 10-h residence timethe concentration has droppedbelow 0.1 mg/liter. Pipe material, in particular cast iron plays animportant role in chlorine reduction (Lu *et al.* 1995; Vasconcelos*et al.*1997; Prévost*et al.* 1998).Chlorinealsonenhances the corrosionprocess.Low concentrations of chlorine are not effective in biofilms andsediments (LeChevallier*et al.* 1988a, 1988b, Herson*et al.* 1991)explainingwhy coliforms may be observed in the presence of a freechlorine residual,. As a consequence, chlorination is causing ashift in the microbial community (LeChevallier*et al.* 1989; Ridgwayand Olson 1982).Gräf and Bauer(1973) isolated a chlorine-resistant *Corynebacterium*from tap water.Thehygienic consequences of these shifts are not clear.These limitations show that chlorine is not the ideal method to limit regrowth indistribution systems. However, the required technology is simple and cheap, andmaintaining chlorine residual throughout the distribution system is an essentialsafety measure when distribution system integrity cannot be assured.

2.9.2Monochloramine

Is used on a large scale for distribution system residualmaintenance and has replaced free chlorine residuals in many supplies in USA. Monochloramine is

less reactive than chlorine, and its application has a number of advantages including less production, limited effect on taste and odour, greater stability in the distributionsystem and relative effectiveness against biofilms (LeChevallier*et al.* 1988b,1990). Finally, monochloramine is less effective than chlorine againstsuspended microorganisms and application may also result in a shift in themicrobial community .The change from chlorine to chloramine in many suppliesindicates thatmonochloramine has certain advantages over chlorine.However, whencompared with systems maintaining quality without disinfectant, the use ofmonochloramine is not attractive.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Study Area

Figure 4:

Map of Khartoum state

Khartoum is one of the eighteen states of Sudan. Although it is the smallest state by area $(22,142 \text{ km}^2)$, it is the most populous (5,274,321 in 2008 census). It contains the country's largest city by population, Omdurman, and the city of Khartoum, which is the capital of the state as well as the national capital of Sudan. The capital city contains offices of the state, governmental and non-governmental organizations, cultural institutions, and the main airport. The city is located in the heart of Sudan at the confluence of the White Nile and the Blue Nile, where the two rivers unite to form the River Nile. The confluence of the two rivers creates a unique effect. As they join, each

river retains its own color: the White Nile with its bright whiteness and the Blue Nile with its alluvial brown color. These colors are more visible in the flood season. The state lies between longitudes 31.5 to 34 °E and latitudes 15 to 16 °N. It is surrounded by River Nile State in the north-east, in the north-west by the Northern Stateintheeast and south east by the states of Kassala, Gedaref and Gezira, and in the west by North Kurdfan. The state is geographically divided into blocks (or clusters), which are further subdivided into localities. There are a total of three blocks and seven localities.

3.2Sampling

Total of150 samples of drinking water were collected during the period fromJanuary to November2013 from differentlocalities in Khartoum State.These samples were aseptically collected in sterile glass bottles, placed on ice, and sent toMicrobiology laboratoryin College of Water and Environmental EngineeringSudan University.

3.3Bacteriology

3.3.1 Colony Count

Total viable count was carried out using the pour plate technique asdescribed by Harrigan (1976). Ten ml of each sample was transferred to nine ml of sterile diluent, as a first dilution, serial dilutions were made up to 9 and 1 ml of each dilution was transferred aseptically in duplicate into sterile Petri dishes. Fifteen ml of melted count agar (45-46°C) was poured into the dishes. The dishes were then thoroughly mixed to facilitate distribution of the sample throughout the medium,and allowed to solidify and plates were incubated at 37°C for forty eight hours. Colony counter (LKB2002.EU) and hand-tally were used for the

determination of the total bacterial counts in terms of colony forming units per ml (C.F.U /ml).

3.3.2 Most probable number test

Presumptive test: The multiple tube fermentation technique was performed as a presumptive test for total coliform using tubes containing MaCconkey Broth and inverted Durham tubes.To each of three double-strength MacConkey broth tubes, 10 ml of the originalsample was added,three single-strength MacConkey broth tubes, 1 ml of the originalsample wasadded, andthree single-strength MacConkey broth tubes, 0.1 ml of the originalsample was added.Incubatedat 37°C forforty eight hours for theobservation of gas production.First reading was taken after 24 hours to record positive tubes, and the negative oneswere incubated for another 24 hours (APHA, 1992).

3.3.3 Membrane Filtration technique

To detect *E. coli,*one hundred ml of drinking water were filtered using membrane filter technique. The filter pad was cultured on a sterile Endo agar plate, incubated at 44.5°C fortwenty four hours. After incubation, the number of red colony- forming units was counted to give the number of *E. coli,* perone hundred ml in the water sample (APHA, 1989).

CHAPTER FOUR

RESULTS AND DESSCATION

4.1Results

Table 4 Mean values and their standard deviations of total viable count of bacteria (CFU/ml) in water in different locations of Khartoum State.

Locality	No. of samples	Mean total viable count of bacteria (CFU/ml)
Khartoum North	42	3.38^a ±0.73
East Nile	40	3.79^a ±0.86
Khartoum	24	3.92^a ±0.48
Gabel Awlia	66	4.12^a ±0.67
Omdurman	20	3.77^a ±0.58
Obadiah	12	3.93^a ±0.49
Karri	55	3.84^a ±0.39
P-value	0.061	
Sig.	No significant difference	

Values are mean±SD Mean(s) bearing different superscript(s) in a column are significantly different (P≤0.05) according to Duncan's Multiple Range Test (DMRT)

Table 5 Mean values and their standard deviations of total coliform (%) in water in different locations of Khartoum State.

Locality	Mean total coliform (%)
Khartoum North	24.06^a ±2.59
East Nile	14.99^c ±1.35
Khartoum	18.93^b ±1.52
Gabel Awlia	3.94^d ±0.81
Omdurman	12.62^c ±1.43
Ombadiah	14.79^b ±1.55
Karri	12.62^c ±1.43
P-value	0.001
Sig.	Highly significant

Values are mean±SD.Mean(s) bearing different superscript(s) in a column are significantly different (P≤0.05) according to Duncan's Multiple Range Test (DMRT)

Table 6 Mean values and their standard deviations of *E. coli* (%) in water in different locations of Khartoum State.

Locality	Mean *E. coli* (%)
Khartoum North	53.61^a ±3.15
East Nile	0.00^e ±0.00
Khartoum	21.27^b ±2.11
Gabel Awlia	0.00^e ±0.00
Omdurman	0.00^e ±0.00
Obadiah	4.68^d ±0.89
Karri	20.42^c ±2.06
P-value	0.035
Sig.	Significant difference

Values are mean±SD.Mean(s) bearing different superscript(s) in a column are significantly different (P≤0.05) according to Duncan's Multiple Range Test (DMRT)

4.2Desscation

Continuous microbiological monitoring of drinking water is essential to ensure compliance with quality standards and to protect public health (Rompre A, Servais P, 2002). The analysis of water samples for total viable bacteria Shows that the treated water samples in most locations contained high number of total viable bacteria however; in general treatment processes leads to decrease number of bacteria at each stationbut the elimination or complete control of bacteria was not occurred. Regulatory agencies and environmental microbiologists have suggested that the heterotrophic bacterial counts in finished drinking water should not exceed from 500 CFU/ml mainly to reduce interference with the detection of *coliform bacteria,* (Environmental Agency, 1989).*Total coliform* were detected in all samples taken from Khartoum water supply the resultswas significantly different between the locations. The coliform group has been used as the standard for assessing fecal contamination of recreational and drinking waters for most of the past century (Gerba, 2000). Coliform bacteria in treated water gave an indication that water treatment system was not operated satisfactorily, or that water became contaminated within the distribution system. In Sudan occasionally sewage networks contaminate water supplies in Khartoum, and up to a million people are infected by several diseases. Health authorities and international relief agencies in Sudan reported more than 5000 cases of diseases caused by drinking contaminated water(Sachs, J., 2001). Khartoum water samples showed the presence of *fecal coliform*, the results was significantly different between the locations. Fecal pollution of drinking water may introduce variety of intestinal pathogens bacterial; those known to have occurred in contaminated drinking water include strains of *Salmonella*, *Shigella*, *Enterotoxigenic Escherichia coli*, *Vibrio cholera*, *Yersinia*

enterocolitica, and *campylobacter Fetus* these organisms may cause diseases that vary in severity from mild gastroenteritis to severe and sometimes fatal dysentery, cholera, or typhoid (WHO, 1984).*Fecal coliform* is very sensitive to disinfectants and their presence may be considered as a major deficiency in the water supply network systems and indicating the recent fecal contamination (Bouwer EJ, Crowe PB, 1988). Sudanese standards for drinking water stated that all water intended for drinking must be free from*E.coli,* or *total coliform*, bacteria in any 100 ml ofwater. This study reveals that water samples were contaminated with greater total and *fecal coliform* bacteria this highlights the need for continuous assessment of the quality of public water supply and intervention measures to prevent outbreak of water by total and *fecal coliform* bacteria.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1CONCLUSIONS

Water derived from Khartoum water supply showed increases in most of the investigated bacteriological parameters this may be highly attributed to the fact that Khartoum water supply at risk of contamination as indicated by the higher levels of most bacteriological parameters.The greater risks in water supply system are deterioration in the distribution system and point of use. This means that more emphasis for improvement at these points rather than at the treatment plant process. It can be concluded that Khartoum water supply contamination varied among locations and it's not suitable for drinking in some location.Improving and expanding the existing water treatment and sanitation systems is more likely to provide good, safe, and sustainable sources of water in the long term. Strict hygienic measures should be applied to improve water quality and to avoid deleterious effects on public health.

5.2Recommendations:

1- Physical and chemical methods for treatment must be improved to enhance the acceptability of drinking water.

2-It is highly recommended to carry out bacteriological examination frequently and regularly for the water entering the distribution system and the water in the distribution system for the control of the hygienic quality of the water supply.

3-Frequent examinations are essential for the piped supplies, it is necessary to maintain a sufficiently high pressure through the whole distribution system to prevent contamination getting into the system; as it is necessary for every

distribution system to have available means of chlorination to deal with accidental pollution, which is always a possibility.

4-Frequent checking of the efficiency of water treatment stations (filtersand tanks) to guarantee cleanliness and suitability of water for drinking.

5-The pipe (Asbestos) in the network distribution must be replaced by PVC. HD or PVC.LD pipes so as to avoid a recontamination resulting from breakdown and degradations.

REFERENCES

Abdelmagid, H.M.; Ibrahim, I.S. and Dirar, H.A. (1984). Chemical Microbiological examination of well and Nile Water. Environmental International, Vol. 10:259-263.

APHA/AWWA/WEF (1998). Standard methods for the examination of water and wastewater. Washington, D.C.: American Public Health Association, American Water Works Association, Water Environment Federation.

APHA (1989). Standard Methods: For the examination of water and wastewater 17th edition APHA, Washington DC, USA.

APHA (1992) Compendium of methods for the microbiological examinations Of foods. 3rd Ed. (Vanderzant, C. and Splittosser, D. eds) Washington, D.C., USA.

Bouwer EJ, Crowe PB. (1988) Biological processes in drinking water treatment. American Water Works Association.pp.: 82– 93.

Burttschell, R.H., Rosen, A.A., Middleton, F.M. and Ettinger, M.B. (1959) Chlorine derivatives of phenol causing taste and odor. *J. Am. Water Works Assoc*. **51**, 205–214.

Caincross S, Feachem R (1993) Environmetal Health Engineering in the Tropic: An introductory text. Second edn John Willey& sons, West Sussex, England.

Cairncross, S. (1987) Water supply and sanitation: an agenda for research. Journal of Tropical Medicine and Hygiene 92, 301–314.

EnvironmentalAgency (2002). The Microbiology of Drinking Water - Part 1 – WaterQualityandPublicHealth.Available at http/www.dwi.gov.uk/regs/pdf/ micro.htm

Gerba, C. (2000). Indicator Microorganisms. In I. P. Raina Maier.*Environmental Microbiology.* San Diego, CA: Academic Press.

Gauthier, F. and Archibald, F. (2001). The ecology of ''Fecal indicator'' bacteria commonly found in pulp and paper mill water systems. Water Research 35(9): 2207–2218.

Gray, N. F. (1994) Drinking water quality: problems and solutions Chichester: John Wiley & Sons Ltd.

Geldreich, E.E., Nash, H.D., Reasoner, D.J. and Taylor, R.H. (1972)the necessity of controlling bacterial populations in potable waters: community water supply. *J. Am. Water WorksAssociation.***64**, 596–602.

Gräf, W. and Bauer, L. (1973) RoterBaktrienaufwuchs (*Corynebaceriumrubrum*n. spec.) in Leitungswassersystemen.*Zentralbl.Bakteriol.Hyg.***157**, 291–303

Harrigan, W.F. and McCance, M.E., 1976. Laboratory methods in Food and Dairy Microbiology, Academic Press, London.

Herson, D.S., Marshall, D.R., Baker, K.H. and Victoreen, H.T. (1991) Association of microorganisms with surfaces in distribution systems. *J. Am. Water Works Association* 83, 103–106.

Lu, C., Biswas, P. and Clark, R.M. (1995) Simultaneous transport of substrates, disinfectants and microorganisms in water pipes.*Water Reaches*. **29**(3), 881–894.

LeChevallier, M.W., Seidler, R.J. and Evans, T.M. (1989) Enumeration and characterization of standard plate count bacteria in chlorinated and raw water Supplies.*AppliedEnvironmentalMicrobiology*. **40**, 922–930.

LeChevallier, MW, Cawthon, CD and Lee, RG. 1988b. Inactivation ofbiofilm bacteria. *Applied Environmental Microbiology*, 54: 2492–2499.

Njiru, C. Albu, M (2004) "Improving access to water through support to small water providing enterprises." *Small Enterprise Development* 15(2): 30-36.

Office of the Provincial Health Officer (2008).Progress on the action plan for safe drinking water in British Columbia.March 18, 2008 British Columbia.Library and Archives Canada Cataloguing in Publication British Columbia. And electronically (in a .pdf file) from: http://www.health.gov.bc.ca/pho/

Payment, P (1999) Poor efficacy of residual chlorine disinfectant in drinking water in distribution systems. *Can. J. Microbiol***45**, 709–715.

Prévost, M., Rompré, A., Coallier, J., Servais, P., Laurent, P., Clement, B. and Servais, P. (1998)suspended bacterial biomass and activity in full-scale drinking water distribution systems: impact of water treatment. *Water Res*. **32**(5), 1393–1406.

Pritchard, M. T. Mkandawre, J. G. and Nell O (2007).Biological, chemical and physical drinking water quality from shallow wells in Malawi.

Rottier E, Ince M (2003). Controlling and preventing disease: The role of water and environmenta sanitation interventions. Water, Engineering and Development Centre, Loughborough University., Leicestershire, UK

Rompre A, Servais P, Baudert J, de-Roubin M, Laurent P. (2002). Detection and enumeration of coliforms in drinking water.

Ridgway, H.F. and Olson, B.H. (1982) Chlorine resistance patterns of bacteria from two drinking water distribution systems.*Applied EnvironmentalMicrobiology*.**44**, 972–987.

Sachs, J. Macroeconomics and health: Investingin health for economic development. *Report of theCommission on Macroeconomics and Health, prepared for WH O 2001*.

Speh, K., Thofern, E. and Botzenhart, K. (1976) UntersuchungenzurVerkeimungvonTrinkwasser. IV. Mitteilung: Das VerhaltenbakteriellerFlächenbesiedlungenineinemTrinkwasserspeicherbeiDauer chlorung. *GWF-Wasser/Abwasser***117**, 259–263.

Trussell, R.R. (1999) Safeguarding distribution system integrity.*J. Am. Water Works Assoc*. **91**(1), 46–54.

Unicef (2006). Unicef Water, Sanitation and Hygiene Strategies for 2006-2015. NewYork: United Nations Economic and Social Council. E/ICEF/2006/6. www.unicef.org/about/execboard/files/06-6_WASH_final_ODS.pdf

Unicef(2008). Handbook on Water Quality 18. , New York.**Unicef**.http: v//www.unicef.org/wash/files/wp.Hand book find–signed 16April 2008.pdf.

Vasconcelos, J.J., Rossman, L.A., Grayman, W.M., Boulos, P.F. and Clark, R.M (1997) Kinetics of chlorine decay. *J. Am. Water Works Assoc*. **89**(7), 54–65.

WHO (1992) Environmental health criteria134, cadmium international program on chemical safety (IPCS), Geneva.

WHO (1996) *Guidelines for Drinking-water Quality*, 2nd edn, vol. 2, *Health Criteria and Other Supporting Information.*World Health Organization, Geneva.

WHO (1997) Guidelines for drinking water quality, 2nd edition, Volume 3,

Surveillance and control of community supplies, World Health Organization, Geneva. pp. 58-61.

World health organization(2003) Regional Office,Pan American for Sanitary Engineering and Environmental SciencesWaterDisinfection.http://www.cepis.ops-oms.org.

WHO (2004) Guidelines for drinking water quality, third edition, volume 1.
WHO/ UNICEF (2000) Global Water Supply and Sanitation Assessment 2000 Report. Geneva and New York: WHO and UNICEF.

WHO & UNICEF (2005) World Health Organization (PDF) Water for Life: Making it Happen.

WHO (2006) Guidelines for drinking water quality: First addendum to 3rd edition WHO Press, Geneva, Switzerland.

WHO (1984) Guideline for Drinking –Water quality Volume (2) Geneva.

World health organization (2008) Guide lines for drinking water quality third edition-volume1 recommendation.

World health organization(2011) Guide lines for drinking water quality fourth edition.

World health organization (2014) Water safety in distribution systems.

World Bank (2009) World Development Report 2009: Reshaping Economic Geography.WorldBank©WorldBank.https://openknowledge.worldbank.org/handle/10986/5991License:CCBY3.0IGO.

Westrell T (2004) Microbial risk assessment and its implications for risk management in urban water systems. Linkoping Studies in Arts and Science, 1:1 edn Linkoping University.

Washington State Department of Health (2011, May) Office of Drinking Water. Retrieved December 2011, from Coliform Bacteria and Drinking Water: http://www.doh.wa.gov/ehp/dw/programs/coliform.htm.