Evaluation of the short- and long- term drinking water sustainability programs for point water sources and public water supplies (PWS) in developing countries: case study of Uganda

Shedrack R. Nayebare
University at Albany, State University of New York, shedracksons@yahoo.com

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Evaluation of the Short– and Long– Term Drinking Water Sustainability Programs for Point Water Sources and Public Water Supplies (PWS) in Developing Countries — Case Study of Uganda.

By

Shadrack R. Nayebare

A Thesis
Submitted to the University At Albany, State University of New York
in Partial Fulfillment of
the Requirements for the Degree of
Master of Science

School of Public Health
Department of Environmental Health Science

2012
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<th>Description</th>
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<tr>
<td>ADF</td>
<td>African Development Fund</td>
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<tr>
<td>BOD</td>
<td>Biological Oxygen Demand</td>
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<td>BGS</td>
<td>British Geographical Survey</td>
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<tr>
<td>CAO</td>
<td>Chief Administrative Officer</td>
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<tr>
<td>CNN</td>
<td>Cable News Network</td>
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<tr>
<td>DBPs</td>
<td>Disinfection By-Products</td>
</tr>
<tr>
<td>DDCBS</td>
<td>District Directorate of Community Based Services</td>
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<tr>
<td>DDHI</td>
<td>District Directorate of Health Services</td>
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<tr>
<td>DDHS</td>
<td>District Directorate of Health Services</td>
</tr>
<tr>
<td>DDT</td>
<td>Dichlorodiphenyltrichloroethane</td>
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<tr>
<td>DEO</td>
<td>District Education Officer</td>
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<tr>
<td>DWD</td>
<td>Directorate of Water Development</td>
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<tr>
<td>DWO</td>
<td>District Water Office</td>
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<tr>
<td>EHD</td>
<td>Environmental Health Division</td>
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<tr>
<td>EIAs</td>
<td>Environmental Impact Assessments</td>
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<td>GAC</td>
<td>Granular activated carbon</td>
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<td>GWR</td>
<td>Ground water Rule</td>
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<tr>
<td>HAA</td>
<td>Haloacetic Acids</td>
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<tr>
<td>IFRC&amp;RCS</td>
<td>International Federation of Red Cross &amp; Red Crescent Societies</td>
</tr>
<tr>
<td>JH</td>
<td>Johns Hopkins</td>
</tr>
<tr>
<td>JMP</td>
<td>Joint Monitoring Program for Water Supply and Sanitation</td>
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<tr>
<td>LVEMP</td>
<td>Lake Victoria Environmental Management Project</td>
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<tr>
<td>MAAIF</td>
<td>Ministry of Agriculture, Animal Industry and Fisheries</td>
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<td>MCLs</td>
<td>Maximum contamination limits</td>
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<td>MDGs</td>
<td>Millennium Development Goals</td>
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<td>MoES</td>
<td>Ministry of Education and Sports</td>
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<td>MoH</td>
<td>Ministry of Health</td>
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<td>MWE</td>
<td>Ministry of Water and Environment</td>
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<tr>
<td>NEMA</td>
<td>National Environmental Management Authority</td>
</tr>
<tr>
<td>NGOs</td>
<td>Non Governmental Organizations</td>
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<tr>
<td>Acronym</td>
<td>Definition</td>
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<tr>
<td>NHP</td>
<td>National Health Policy</td>
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<td>NTUs</td>
<td>Nephelometric Turbidity Units</td>
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<td>NWDR</td>
<td>Uganda National Water Development Report</td>
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<tr>
<td>NWP</td>
<td>National Water policy</td>
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<tr>
<td>NWSC</td>
<td>National Water and Sewerage Corporation</td>
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<tr>
<td>PCBs</td>
<td>Polychlorinated Biphenyls</td>
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<tr>
<td>PEAP</td>
<td>Poverty Eradication Action Plan</td>
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<tr>
<td>POPs</td>
<td>Persistent organic pollutants</td>
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<tr>
<td>PRC</td>
<td>Performance Review Committee</td>
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<tr>
<td>PVC</td>
<td>Poly Vinyl Chloride</td>
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<tr>
<td>RWSS</td>
<td>Rural Water Supply and Sanitation</td>
</tr>
<tr>
<td>SDWA</td>
<td>Safe Drinking Water Act</td>
</tr>
<tr>
<td>SODIS</td>
<td>Solar water disinfection</td>
</tr>
<tr>
<td>SWAP</td>
<td>Sector-Wide Approach to Planning</td>
</tr>
<tr>
<td>THMs</td>
<td>Trihalomethanes</td>
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<tr>
<td>TOC</td>
<td>Total Organic Carbon</td>
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<tr>
<td>U.S. EPA</td>
<td>United States Environmental Protection Agency</td>
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<tr>
<td>UBOS</td>
<td>Uganda Bureau of Statistics</td>
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<tr>
<td>UNEP</td>
<td>United Nations Environment Programme</td>
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<tr>
<td>UNICEF</td>
<td>United Nations Children’s Fund</td>
</tr>
<tr>
<td>URCS</td>
<td>Uganda Red Cross Society</td>
</tr>
<tr>
<td>URN</td>
<td>Uganda Radio Network</td>
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<tr>
<td>USGS</td>
<td>United States Geographical Survey</td>
</tr>
<tr>
<td>UVP</td>
<td>Uganda Village Project</td>
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<tr>
<td>UWSS</td>
<td>Urban Water Supply and Sanitation</td>
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<tr>
<td>WAU</td>
<td>Water Aid- Uganda</td>
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<tr>
<td>WFP</td>
<td>Water for Production</td>
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<tr>
<td>WHO</td>
<td>World Health Organization</td>
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<tr>
<td>WRAP</td>
<td>Worldwide Responsible Accredited Production</td>
</tr>
<tr>
<td>WRM</td>
<td>Water Resources Management</td>
</tr>
<tr>
<td>WUGs</td>
<td>Water user groups</td>
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</table>
Abstract
Providing quantity and quality potable water in Uganda and other developing countries is still significantly problematic. This project aimed at identifying and prioritizing possible actions on how sustainable and high quality potable water in Uganda’s water supply systems could be improved. A review of both the current water supply systems and Ugandan government programs was completed in an effort to describe the existing state of Uganda’s water supply. Aspects of quantity, quality, treatment methods, infrastructure, storage and distribution of water for the different water systems were assessed. These characteristics were compared to water supply systems and regulations in the U.S., Latin America, and the Caribbean, so as to come up with feasible recommendations on the potential opportunities for improving Uganda’s water supplies.

Uganda utilizes surface water, ground water and rain water. Surface water covers 15.4% of land area and serves both urban and rural populations. Lake Victoria, contributes about 85.2% of the total fresh surface water. Potable water quality is affected by sewage disposal, industrial effluents, agricultural pesticides and fertilizers, and surface runoffs/floods during heavy rains/El-Niño. The total renewable ground water resources in Uganda are estimated at 29 million cubic meters per year (m³/year) with approximately 20,000 boreholes, 3000 shallow wells and 200,000 springs, serving more than 80% of the rural and poor urban-slum communities. Average annual rainfall ranges from 500 mm to 2500 mm. Ground water and collected rain water quality is mainly affected by poor sanitation and hygiene practices. There are regional variations in potable water accessibility with Northeastern region having the least quantity of water from all sources.

Generally, Uganda still lags behind in potable water resource development. Priorities should focus mainly on easy measures available for improvement of ground water and rain water resource utilization; protection of watersheds; health education; improved water treatment methods and distribution in rural areas; and pollution control so as to revitalize water accessibility especially to the poor populations living in rural and urban slum areas, since they comprise the majority (80%) of Uganda’s population.

Keywords: Water Systems (Surface, Ground and Rain water), Government Legislations, Potable water, Water Disinfection, Water Distribution, and Water Pollution.
Introduction

Main Objective of the Study

To identify the potable water quality, quantity and accessibility issues in Uganda and thus generate recommendations to the Ugandan government on how to improve the potable water supply systems.

Specific Objectives

1. Reviewing the potable water supply systems (for Surface water, Ground water & Rain water sources) and the pertaining Government Regulation on water supply in Uganda
2. Reviewing potable water supply programs & Regulations in other countries (i.e. the U.S., Latin America and the Caribbean)
3. Comparing of Uganda to other countries from objective 2, and highlighting the major differences in approaches to water supply with regard to the available water sources
4. Recommending the potential opportunities for improving drinking water supplies in Uganda and provide an analysis of the cost-benefit and obstacles present to implement the recommended activities; and
5. Generating a list of feasible priority activities/plan-of-action that can be implemented to improve Uganda’s water supplies from the various water sources (Surface water, Ground water, and Rain water)

Materials and Methods

A review of both the current water supply systems and the Ugandan government programs was completed in an effort to describe the current state of Uganda’s water supply. Aspects of quantity, quality, treatment methods, infrastructure, storage and distribution of water for the different water systems were assessed. These characteristics were compared to water supply systems and regulations in the U.S., Latin America, and the Caribbean. These countries were considered on the basis that; the U.S. is a developed country setting and thus has more efficient water supply programs and legislation than Uganda. In addition, a lot of research in water development has been carried out in the
U.S. and would thus provide the best and applicable programs in water supply and legislation which could easily be used to suggest improvement in Uganda. On the other hand, Latin America and the Caribbean countries have developed metropolitan areas, slums and rural populations which are comparable to Uganda and many other developing countries, thus it would be easier to borrow a leaf from what has been successfully implemented and is being practiced in these countries, and recommend application in Uganda. Information/data were obtained from previous studies.

An analysis of cost-benefit and obstacles present to implementation of the activities aimed at improving water supplies in Uganda was carried out so as to establish recommendations on a feasible plan–of–action that can be applied in Uganda and other developing countries regarding improving water supplies.

**Background and Significance of this Project**

Providing sustainable quality and quantity potable water to the whole population in Uganda and many other developing countries in Sub–Saharan Africa and Asia is still a significant problem. There are intermittent shortages in quantity and quality water in Uganda, and those that have a continuous supply are served water originating from eutrophic surface water sources. To date, the goal of water supply in Uganda has been to improve the accessibility and continuity of the supply and to deal with the acute health concerns pertaining water quality issues (i.e. microbial contamination, color, turbidity, etc.). As the water supply develops and improves, more emphasis may be placed on the chronic health concerns associated with contaminants such as the disinfection by–products (DBPs). Thus, this project is to basically help prioritize the needs and the possible plan–of–action/activities for improving Uganda’s water supplies.
1.0. Chapter one

1.1. Water Supply Systems and Government Regulation on Water Supply in Uganda

1.1.1. Surface water

1.1.1.1. Sources

1.1.1.1.1. Quantity and Utilization

Uganda has a vast number of lakes, rivers and streams. However, accessibility to sufficient quantity and good quality drinking water is still a major issue for most parts of Uganda, especially among the rural and poor urban communities. Uganda’s surface water sources cover 36,330 square kilometers (km\(^2\)) –15.4 percent (%) of the total land area (236,040 km\(^2\)) and these provide domestic water supply to both urban and rural populations. Lake Victoria, with an area of 68,800 km\(^2\) is the second largest freshwater lake in the world and contributes a significant proportion (30,960 km\(^2\) –85.2%) of the total available fresh surface water in Uganda. The lake is shared between Uganda, Tanzania and Kenya in the proportions of 45%, 49% and 6% of the surface area respectively (Wilfred, 2001).

![Figure 1 — Map of Uganda showing the Main Lakes and Rivers; and their Regional Distribution](http://mapsof.net/map/rivers-and-lakes-of-uganda)

The largest proportion (>50%) of people living in major towns and cities in Uganda utilize water supplied by the National Water and Sewerage Corporation (NWSC) which basically obtains its raw water from lakes nearby the respective towns. Domestic water
supply in such scenarios is through piped household water connections and communal tap stands at a fee/tariff set by NWSC itself and approved by the Ministry of Water and Environment (MWE).

In rural and poor urban communities, surface water is obtained from rivers, streams, swamps, seepages and ponds. Sometimes in those regions with extreme water accessibility concerns (e.g. in northeastern region– Karamoja), rain floods are a source of domestic water. Some of the surface water in the rural areas comes from unprotected springs which form stagnant ponds. Many surface water sources in the rural areas are seasonal and thus are mostly utilized during the rainy/wet seasons of the year except for those who live near fresh water lakes.

![Figure 2](image)

**Figure 2**—Some of the surface water sources utilized in rural communities in Uganda [Seepages, Ponds, Swamp water, Rivers, Streams, Rainfall runoffs, etc.] (URN, 2008; UVP, 2009)

1.1.1.1.2. Quality Issues
Pollution of surface water sources in Uganda and indeed many other countries around the world remains a major obstacle to access safe domestic water supply. Anthropogenic activities (e.g. agriculture, industrialization, etc.) are major contributors of pollution to surface water sources in Uganda. Most of the available fresh surface water sources in the Uganda rate poorly in terms of bacteriological and chemical quality assessments. Below is a summary of the water quality issues with Uganda’s surface water sources.

The quality of surface water in most of Uganda’s major lakes is believed to be similar to that from Lake Victoria. This is mainly due to the similarities in the pollution activities (waste water treatment plants, and fishing populations discharging sewage into the lakes, etc.) on the lakes and along the shores. In addition the pollution that occurs on Lake Victoria is easily carried to other major lakes (L. Kyoga and L. Albert) since the main
influent river (River Nile) of these lakes flows from Lake Victoria and there isn’t a long distance separation between these lakes. Besides, Lake Victoria contributes the largest proportion (approximately 85%) of the available surface water in Uganda; and serves a significantly large population as indicated below.

NWSC gets its raw water from Lake Victoria and serves about 12 districts around central Uganda and the lake basin area (>10 million people–UBOS, 2011). The lake is eutrophic due to excessive inflow of nutrients (such as; phosphorous and nitrogen) over a long period of time which has promoted algal growth (Bekithemba, 2005). There is a 5-fold increase in algal growth on the lake since the 1960s (LVEMP, 2005; Tamatamah et al., 2005). The lake water appears green due to excessive growth of water hyacinth that has boosted the Total Organic Carbon (TOC) and also deteriorated the bacteriological quality of lake water by serving as repositories for waterborne pathogens (Muyodi et al., 2003).

Figure 3—Water Hyacinth on Lake Victoria and the green appearance of the lake water (with permission from Australian Broadcasting Corporation –ABC, 2000)

Water pollution on Lake Victoria is primarily due to the discharge of raw/partially treated sewage from Bugolobi sewage treatment plant and Luzira prison, dumping of domestic and industrial chemical and organic waste, and fertilizers from several agricultural farms in the lake basin; that is characterized by densely populated cities, towns and villages that are home to many factories and industries. Kampala city, the capital of Uganda is located within the catchment area of Lake Victoria. Because most of the swamps (wetlands) around the lake have been cleared for farming and human settlement, the industrial discharge and storm water containing street waste from this city flows untreated into the Nakivubo channel which drains directly into L. Victoria’s Inner Murchison Bay (Kansiime and Van Bruggen, 2001).
The lake also has inhabited islands (3,000 Ssese Islands) and fishing populations who dump their excreta directly into the lake and thus contributing significant amounts of TOC and a heavy load of pathogenic microbes to the lake water. In addition, there are several other medium-to-large scale industries and numerous small-scale enterprises located on the Lake Victoria catchment area; these discharge high organic, nutrient-rich effluent loaded with metal pollutants into the bay (LVEMP, 2001) without any prior onsite pre-treatment.

At the Nakivubo channel discharge point into the lake, the Biochemical Oxygen Demand (BOD) is greater than 3.5 milligrams per liter (mg L\(^{-1}\)) indicating significantly polluted water with respect to organic loading; and phosphorus concentrations are in the range of 1.0–4.0 mg L\(^{-1}\) which is way above the World Health Organization (WHO) recommended maximum level for surface water (0.1 mg L\(^{-1}\)). These data substantiate the occurrence of intensive algal bloom (with chlorophyll-a concentrations >20 mg L\(^{-1}\)) within the bay (Oyoo Richard, 2009). The high levels of organic matter have contributed to the intensive color, turbidity levels of up to 84.0 Nephelometric Turbidity Units (NTUs) and undesirable pathogenic microbes in the lake water (Balirwa et al., 2009). The humic component of turbidity is the foremost precursor of disinfection by-products (DBP) formation if the water is chemically disinfected; and can also lower the effectiveness of disinfection processes using chlorine (Darby et al., 1995) since excessive turbidity can protect pathogenic microorganisms from the effects of disinfectants and thus increase chlorine demand, as well as promoting microbial growth along the distribution.

Looking at the quality of surface water in the rural and poor urban communities, the major issues are with the bacteriological quality that usually stems from poor hygiene and sanitation practices characterized by widespread use of poorly constructed and sited pit latrines, dilapidated sewage systems, and sometimes the complete absence of sanitation.
facilities (pit latrines) where people use open fields for defecation which immensely pollute both surface water and shallow ground water sources (JH and IFRC&RCS, WHO/UNICEF and JMP, 2012). Considering the nature of the available surface water sources as shown in the figure 2 above, and the pertaining sanitation conditions in slums and rural communities of Uganda, fecal contamination of water sources with both human and animal feces remains a major challenge to supply of quality domestic water from surface water sources to such communities. Besides, majority of the people living in rural Uganda communities are mostly poor living under the poverty line (<1US$ per day). This has greatly impacted on implementation of several activities aimed at improving quality water supply in most rural and poor urban communities in the country.

1.1.1.2. Treatment processes and Storage
1.1.1.2.1. Surface water Treatment
1.1.1.2.1.1. Filtration
Surface water filtration is usually applied by the National Water and Sewerage Corporation (NWSC) during the treatment of raw water for municipal water supplies in urban areas (major towns and cities). Filtration of water obtained from the surface water sources in rural and poor urban communities is not a common practice and thus the water is used as it’s obtained from the water source. Depending on the intended use, this water may or may not be disinfected prior to use. Surface water disinfection methods used in Uganda are discussed in the next section.

At the NWSC, filtration of water is done in three stages; the first 2 stages are referred to as screening stages (coarse screens/ trash racks and inlet screens) and the 3rd stage is termed rapid gravity filtration. The NWSC uses the following treatment processes: screening, coagulation, flocculation, sedimentation and rapid gravity filtration as described in more details below:

Screening: Two sets of mechanical steel screens are used to screen the raw water. The first set of the screens is the coarse screens (trash racks) made of large bar racks spaced 1–3 inches apart and are installed at the inlet point into the treatment plant. They are intended specifically to prevent large organic and un-decomposed materials (e.g. wood pieces, dead fish, etc.) that could damage the intake structure and other equipment from
entering the treatment system. Bar racks are typically designed for manual cleaning. Though trash racks have little effect on turbidity, they help to keep large solids out of the treatment system.

The second set are the intake screens and are similar to bar racks and generally perform the same function except that, they have smaller openings (3/16–3/8 inch wide). Intake screens are usually fitted with mechanical or hydraulic cleaning mechanisms since they remove particles much smaller than those removed with bar racks. These screens may provide some turbidity reduction by removing larger solids that may be a source of smaller particles later in the treatment process (U.S. EPA, 1999). After screening, the water then goes through coagulation, flocculation and sedimentation before it is filtered;

**Coagulation:** Basically, coagulation is the destabilization of colloids (suspended particles) by neutralizing the forces that keep them apart and thus promoting their agglomeration to produce larger particles that can be easily removed in subsequent treatment processes (U.S. EPA, 1999; Henry H.B. Jr. et al., 2001; AWWA and ASCE, 1998). Coagulation is typically accomplished through addition of chemical/coagulant and rapid mixing to destabilize the forces that keep the colloids apart.

After water with suspended colloids/particles that has passed the screening stage, is dosed with alum [aluminum sulfate – Al$_2$(SO$_4$)$_3$] at a relatively low dose –less than or equal to 5 mg L (Techneau, 2006; Qin et al., 2006) to facilitate the agglomeration of the colloidal particles to form larger particles that can easily be removed from the water (Bratby J., 2006; U.S. EPA, 1999). Charge neutralization/destabilization is believed to be the primary mechanism involved to facilitate agglomeration. Cationic coagulants [Al$_2$(SO$_4$)$_3$] provide positive electric charges to neutralize the negative charge of the colloids. As a result, the particles collide to form larger particles (flocs). The water is mixed rapidly to effectively disperse the coagulant throughout it. A lot of care is usually needed to determine the coagulant dose because an overdose can cause a complete charge reversal and re-stabilize the colloid complex, which makes it hard to remove from the water. At higher dosages, the primary coagulation mechanism is entrapment. In this case, aluminum hydroxide [Al(OH)$_3$] precipitates forming a “sweep-floc” which captures suspended solids as it settles out of suspension (U.S. EPA, 1999; Henry H.B. Jr. et al., 2001). The sweep is occurring as the suspended solids settle. There is a pH monitor for
the inflowing raw water and this helps to maintain a favorable pH for the solubility of aluminum species in water since alum is used as a coagulant. If the pH value between 4 and 5, alum is generally present in the form of positive ions \([\text{Al(OH)}^{2+}, \text{Al}_8(\text{OH})^{4+}, \text{and Al}^{3+}]\). However, optimum sweep and sweep coagulation occur when negatively-charged forms of alum predominate, which occurs at pH value between 6 and 8 (EPA, 1999; AWWA and ASCE, 1998; Henry H.B. Jr. et al., 2001).

**Flocculation:** After the raw water has been dosed with alum \([\text{Al}_2(\text{SO}_4)_3]\) and gone through coagulation, it then flows into the flocculation chamber where the coagulated flocs further agglomerate and form macro-flocs or larger particles that can easily settle out of the water by sedimentation process (Bratby J., 2006; Henry H.B. Jr. et al., 2001; U.S. EPA, 1999). The retention time of water in the flocculation process is usually between 10 and 30 minutes. Typically, flocculation is the physical process of agglomerating small particles into larger ones that can be more easily removed from suspension. Flocculation is mostly used in combination with, and preceded by coagulation (Henry H.B. Jr. et al., 2001; U.S. EPA, 1999). During the coagulation process the repulsive forces between solid particles are neutralized or removed; and in flocculation process, the destabilized particles are brought into contact with one another to form larger “floc” particles that are more readily removed from the water in subsequent processes. Flocculation takes place when polymers (floculants) form bridges between the flocs and bind them into large agglomerates called the macro-flocs. Bridging occurs when segments of the polymer chain adsorb on different particles and help the particles to aggregate (Henry H.B. Jr. et al., 2001). Alum which is a cationic flocculant will react against a negatively charged suspension, adsorbing on the particles and causing destabilization either by bridging or charge neutralization (Henry H.B. Jr. et al., 2001; U.S. EPA, 1999).

Throughout the flocculation process, it is essential that the water is not rapidly flowing because the newly formed agglomerated particles or macro-flocs are very fragile and can easily be broken. Shear forces of rapidly flowing water will break apart the macro–flocs. Precaution must also be taken not to overdose the polymer as this can cause settling problems. In addition, polymers used for bridging are typically lighter than water and as such; overdosing will result in an increased tendency of the flocs to float and fail to settle.
There are several factors that determine the efficiency of coagulation and flocculation processes. These may include but are not limited to the following; type and dosage of coagulant, pH, flocculator retention time, water flow, intensity and duration of mixing at rapid mix stage, etc.

**Sedimentation/Clarification:** Once suspended particles are flocculated into larger particles or macro-flocs that are denser than water, they are then removed from the water by gravitational settling and sedimentation. Some of these particles are removed using sand filtration by rapid gravity filtration. Technically, settling is the falling of suspended particles through the liquid/water, whereas sedimentation is the termination of the settling process.

Sedimentation can also be defined as the tendency for particles in suspension to settle out of water in which they are entrained, and come to rest against a bottom barrier. This is due to their motion through the fluid in response to the forces acting on them: these forces can be due to gravity, centrifugal acceleration or electromagnetism. Sedimentation process for NWSC water treatment plant used at Gaba water works is by gravitational settling. During sedimentation, water passes through a sedimentation tank (clarifier) with little disturbance, where the floc particles formed during flocculation settle to the bottom of the clarifier. The clear water passes out of the clarifier over an effluent baffle into the rapid gravity sand filtration bed. The solids collect on the bottom of the clarifier and are removed by a mechanical “sludge collection” device and pumped directly to the sludge drying beds. Basically the NWSC water treatment plants use conventional sedimentation and have more than 2 rectangular clarifiers each. The water has a high velocity at the inlets but it gradually reduces towards the outlet. The clarifiers are also shallow at the inlets and get deeper and deeper towards the outlets. This design is meant to ensure quiescent conditions in the clarifiers to promote settling.

**Rapid gravity filtration:** After the water has gone through the coagulation, flocculation and sedimentation processes which remove most of the suspected colloidal particulates, it is then allowed to trickle through a filter bed made of fine lake sand by rapid gravity filtration process. This helps to further strain out any suspended particles from the water and to also retain most of the microorganisms that will have survived all the initial
processes of flocculation and sedimentation before the water is chemically disinfected by chlorination. The sand filter bed is maintained by periodically scrapping off the clogged upper layer of sand and replacing it with clean lake sand. The sand filter is also cleaned by backwashing. The frequency of cleaning the filter bed depends mainly on; the amount of water filtered per day and the quality of raw water being filtered through, but usually it is done after a maximum of 72 hours of constant operation (NWSC, Uganda; U.S. EPA, 1999).

1.1.1.2.1.2. Disinfection of Surface water
Disinfection methods applied for surface water in rural Uganda are typically different from those applied in urban areas. The urban populations in Uganda mainly utilize water piped by NWSC which is chlorinated prior to distribution. However, due to numerous distribution system failures as observed in most urban centers, where water and sewage pipes can leak for several days before they are fixed, the people are always advised to boil their water before it is consumed. In some places, the water pipes are very close to sewer lines which makes contamination of water more probable in case of any leakages.

At the NWSC water treatment plant, the method of disinfection applied is chlorination. The dose of chlorine is determined in such a way that a minimum biocide residual concentration of 0.5 mg L\(^{-1}\) is maintained throughout the distribution system. However, for most part this is never attained in practice. At the treatment plant, the quality of treated water is monitored with the goal of producing water with the following characteristics: pH 6.7–7.2; true color <15 PTU; turbidity <5 NTU; NH\(_4^+\) <1.5 mg L\(^{-1}\); NO\(_3^-\) <50 mg L\(^{-1}\); SO\(_4^{2-}\) <250 mg L\(^{-1}\); and total coliforms– 0 counts/100 milliliters [ml] (WHO, 2008; NWSC, Uganda).

In the rural and poor urban slum communities, the methods of surface water disinfection used are similar to those discussed under “Ground water section” below. They include but are not limited to; boiling, chlorination by use of chlorine tablets (water guard), and solar disinfection (SODIS). However, for those communities with access to Surface water and ground water, the preferred and thus utilized water sources are usually ground water. Ground water is typically more aesthetically appealing than surface water and is thus perceived as safer.
1.1.1.2.2. **Storage**

There is no organized storage of water used for domestic purposes in rural and poor urban communities. Most of the populations in these communities obtain their water from the water-source in relatively small containers with capacities ranging from 5–20 liters and that is where water is stored and used. A few households will occasionally have water storage tanks of about 100 liters capacity or more. Consequently there is a lot of time lost for the school going children since they are the ones who routinely collect the water from distant water sources of up to 4 kilometers for their families (*The African Timer, 2011*).

In the urban areas, especially those connected to piped water by NWSC, individual households usually have water storage tanks installed. The capacity of the tank installed usually depends on what the owner can afford. The capacity of the water storage tanks usually ranges from a few hundred liters to thousands of liters. The water treatment plants also have water storage tanks corresponding to the daily output of the treatment plant and these help to ensure steady supply of water just in case of a break down in production. For example the NWSC, Gaba III water treatment plant produces 80,000 cubic meters ($m^3$) daily and has storage tanks which can store in excess of that amount of water in five different locations in Kampala City (*NWSC, 2008*).

1.1.1.3. **Distribution**

There are very huge regional disparities in distribution of surface water sources in Uganda. Most of the surface water sources (lakes and rivers) are mainly in the central, southern, eastern and western regions of the country as indicated in figure 1. In the Northern and Northeastern regions of Uganda, the available rivers are mainly seasonal and will flow only during heavy rains. The quality of the water in such rivers is usually poor as they normally carry surface runoffs. Utilization of surface water in these regions is not widespread as it is not available for most of the year. The people in these regions mainly depend on ground water from deep wells (≥ 30 meters deep), which are also not sufficient in number. Generally, the problem of water inaccessibility in these areas especially the Northeastern region is much more severe than any other part of the country.
1.1.2. Ground water

1.1.2.1. Sources

1.1.2.1.1. Quantity and Utilization

The advancements in ground water development and utilization in Uganda started as early as the 1930s by drilling of new deep boreholes, shallow wells, protection of springs and rehabilitation of old and faulty water sources (NWDR, 2005). The total renewable ground water resources in Uganda are estimated at approximately 7.661 billion gallons/year [or 29.0 million m$^3$/year] (Syngellakis and Arudo 2006). There are an estimated 20,000 deep boreholes, 3000 shallow wells, 12,000 protected springs (NWDR, 2005) and over 200,000 springs (DWD, 1994) in rural Uganda that serve for domestic water supply. Ground water from boreholes and springs is the most important potable water source for the people in rural communities of Uganda especially in the Eastern and Northern regions and provides more than 80% of the water supply (BGS and WAU, 2001). In addition, ground water is also utilized for livestock production particularly in dry regions of Uganda. Improvements in ground water development for urban water supply have also been recorded since early 1990s owing to the need for water supply systems that are manageable to the users (NWDR, 2005).

![Figure 4—Protected Shallow Ground water Sources (springs) in Bwaise III, one of the Poor Urban Slum Areas of Kampala City Uganda (Kulabako et al., 2011)](image)

1.1.2.1.2. Ground water Quality Issues in Uganda

The foremost ground water-quality problem in Uganda is associated with bacterial contamination resulting from poor sanitation facilities (Water Aid- Uganda, 2001; Tinimuguya, 2011). Fecal coliforms and high nitrate [$\text{NO}_3^-$] concentrations have been found in some ground water sources especially in the poor urban slum areas. Coliform counts are higher in ground water especially the shallow ground water which is affected by localized pollution (DWD, 1994) from the numerous poorly located pit latrines and
poor drainage systems as evidenced in most poor urban slum areas in Uganda. In Kampala City, the capital of Uganda, only 55% of the population is supplied with piped water, out of which only 9% is connected to the sewerage system and this means that the rest use pit latrines which pollute shallow ground water sources in such areas.

Although ground water from springs has for long been considered aesthetically acceptable and safe for domestic use, the issues of poor sanitation activities characterized by poorly sited pit latrines, poor drainage and waste (liquid & solid) management systems and inadequate spring protection as evidenced in most urban slum areas in Uganda and other developing countries, have been implicated in the perpetual contamination of this ground water with pathogenic microbes and nitrates. Nitrate (NO\textsubscript{3}–) concentrations in Uganda’s ground water vary from place to place but can be challenging in some areas where high NO\textsubscript{3}– concentrations of up to 26 mg L\textsuperscript{–1} as nitrogen were reported as early as the early 1990s (Taylor and Howard, 1994) and most of this NO\textsubscript{3}– contamination is mainly linked to poor sanitation practices, since agricultural application of NO\textsubscript{3}– is not yet widespread in Uganda.

**Figure 5**—Deplorable Housing, Raised Pit Latrine with Solid waste dumping in the foreground and a Sullage/Storm water drainage channel with Solid waste dumping at the banks in Bwaise III slum Kampala City (Kulabako et al., 2011)

Ground water from shallow wells (with high water tables) is the most at risk from pollutant inflows since there isn’t enough soil filtration of the water to remove the pollutants before reaching the aquifer. As such, the ground water from dug wells and springs has been found to be of poorer quality than the water from deep boreholes (DWD, 1994) since the deep borehole water undergoes thorough soil filtration before it finally reaches the aquifers in deep rock formations. As a matter of fact, if properly maintained (e.g. through improved hygiene and sanitation practices), the quality of ground water
from boreholes is good enough even without any disinfection. From a pilot study about the quality of water from protected springs in Kampala city, 90% of the springs studied had total coliform counts that exceeded the drinking water guidelines by WHO (Haruna et al., 2005). However, where deep boreholes are used, bacterial contamination at the water source is usually limited, though the water may get contaminated as a result of poor domestic sanitation and hygiene standards which characterize most low-income/poor communities. Despite these water-quality problems, ground water supply systems remain the most important and feasible source of safe drinking water in rural Uganda since they require little or no treatment unlike surface water. In summary, the investment and operational costs of ground water systems are considerably less than those of surface water systems and thus can more likely be afforded in rural and poor urban communities.

![Figure 6](image.png)

**Figure 6**—A properly maintained and protected borehole (deep ground water source) drilled by a Water-Aid Uganda community based project in Katakwi District Eastern Uganda (Water–Aid Uganda, 2011)

Chemical contamination of ground water in Uganda is still very low since industrial development isn’t yet widespread in the country and the application of pesticides and fertilizers for agricultural production is still very low in the rural communities where there is a significantly high dependence on ground water as a drinking-water source. Fluoride seems to be one serious inorganic contaminant in Uganda’s ground water and is mainly linked to volcanic soils and rocks. For example, the crater lakes of western Uganda have often been found to have high fluoride concentrations of up to 4.5 mg L$^{-1}$ or more (BGS and WAU, 2001; Mungoma, 1990) and these high concentrations are also found in ground water in the neighborhoods of these lakes. High fluoride concentrations exceeding 1.5 mg L$^{-1}$ (WHO guideline) have also been measured in ground water from Rift Valley and Rwenzori Mountains of Western Uganda; the volcanic areas of the
Eastern Uganda (Sukulu Hills and Elgon areas in Mbale), and in and the Northeast (Moroto areas) where the incidence of fluorosis is known to be habitually high (WRAP, 1999).

1.1.2.2. Ground water Treatment processes and Storage

1.1.2.2.1. Ground water Treatment

1.1.2.2.1.1. Filtration

Filtration of ground water is not a wide spread practice in Uganda. In most cases the water is just drawn from the ground and used without any treatment. This is mainly because; the ground water especially from the deep boreholes is clear and subsequently appears not to need filtering before it is used or even before chlorination as the case may require. Generally if the water source is deep, protected and the pump maintained in a sound condition, ground water will barely have any suspended particles. Use without any treatment is acceptable.

1.1.2.2.1.2. Disinfection

In Uganda, ground water is mainly obtained from point water sources, and its use has not yet been applied on commercial scale by municipal water supply systems. As a result any water treatment/disinfection done on this water is mainly home based with a few exceptions where water decontamination is done at the water source mainly during epidemic outbreaks of serious waterborne diseases like cholera, hepatitis E, etc. there are several treatments that are currently being used to decontaminate drinking water at household level in Uganda as highlighted below;

The most common method used countrywide is boiling the drinking water. The water is boiled up to full rolling boil point at 100 Degrees Celsius (100°C or 212°F) for at least one minute and later allowed to cool down under clean conditions before it is used. It may take about 15 to 20 minutes to reach the full rolling boil point depending on the amount of water. This is mainly applied in areas where chemical disinfection is not available and where other resources like firewood that are needed to boil the water can be obtained freely or cheaply. Boiling as a method of drinking water disinfection is effective at killing most pathogens in water. However, the big limitation is that, the water can readily get re-contaminated if not handled properly because boiling doesn’t provide any biocide residual. In addition, the process of water boiling uses resources, is very tedious
and time consuming and as such people tend to use it less frequently. In some other communities, the hygiene and sanitation standards are very low which makes it impossible to depend on boiling drinking water as a method of controlling waterborne diseases. Another point to note is that; if the water has been chlorinated prior to boiling, boiling will provide no protection against some chemical contaminants (DBPs) in the water. For example, boiling can reduce the concentration of volatile THMs but has no effect on di-halogenated haloacetic acids in water (Krasner and Wright, 2005).

Chlorination is also applied for home-based/ household level drinking water treatment in the rural Uganda areas in form of chlorine tablets (calcium hypochlorite) and sodium hypochlorite solutions – under the trade name of “water guard” supplied mostly by the NGOs and can also be commercially available chemical stores. In this case, 1–2 tablets are added per liter of water and allowed to react for about 25–30 minutes before use. This method of drinking water disinfection has been frequently used during the several waterborne diseases (e.g. cholera, hepatitis E, etc.) epidemics in several parts of Uganda especially in the eastern and northern regions as well as among the poor urban folks living in slums. Most of the chlorination is provided by the NGOs operating in the rural communities where they provide drinking water accessibility services. Chlorine application on household level can be tricky, because the people need to thoroughly understand the conditions under which chlorine should be applied otherwise there will be exposures to chemical contaminants (such as DBPs) in the water especially where the water contains organic matter. Chlorination cannot effectively disinfect the water if there is a certain level of turbidity in the water. As such, people need to be thoroughly enlightened on how and when to apply chlorine.

**Figure 7**—Trained Uganda Red Cross volunteers conducting potable water chlorination at boreholes in return sites in Agoro sub-county, Kitgum District, Uganda (URCS, 2008)
Solar Drinking Water Disinfection (SODIS) is another method used for water disinfection but its application is not publicized/popular enough in the country. This method involves subjecting untreated water in small and transparent containers of about 1–3 liters (0.001–0.003 m$^3$) in capacity, to direct sunlight for varying periods of exposure (usually up to 6 hrs.). The concept is that; most pathogens of fecal origin in water will die off if exposed to the UV radiation in sunlight for a significant period of time. There are many concerns on the efficiency of this water disinfection method as different studies have shown different/controversial results. A cluster-randomized, controlled trial (Mäusezahl et al., 2009) about the use of SODIS to Reduce Childhood Diarrhea in rural Bolivia, found no statistically significant difference between the number of diarrhea episodes per year among the children in the intervention group (3.6 episodes) and in the control group (4.3 episodes). In another randomized controlled intervention study in Kenya (Preez et al., 2011), the children consuming exclusively SODIS-treated drinking water were found to be; not only less affected by diarrhea, but also physically more developed than children of a control group who drank untreated water. This method of water disinfection would probably be affordable and applicable especially in rural Uganda due to the favorable climate. However, more community education on the application of SODIS as a method of water disinfection needs to be intensified if we are to achieve positive results as per the control of diarrheal diseases.

Figure 8—Application Methods of SODIS in developing countries (Preez et al., 2011; CNN–Kenya, 2012; Monika Tobler, 2011–
http://www.sodis.ch/index_EN accessed April, 2012)

From the pictures in Figure 8, it’s very clear that; the differences in the outcomes of studies on the application of SODIS for control of waterborne diarrheal diseases, basically originate from poor application of the method. Whereas some places do it the right way, others are doing contrary as indicated above. This could be the reason for the
observed differences in findings from different studies about the use of SODIS to control waterborne diarrheal diseases.

1.1.2.2. Storage of Ground water

In Uganda’s rural communities utilizing ground water, water is mainly stored in the same containers used for collection from the source. The capacity of such containers ranges from 5–20l [or 0.005–0.02 m³]. People basically don’t have big tanks where a big volume of water can be collected and stored; as such going to the water source to collect water is a daily routine mainly for children and women in the community. The lack of adequate water storage facilities coupled with inadequate number of and distant [up to 4 kilometers] (The African Timer, 2011) water points in most rural communities, has been one of the major causes of long queues at the water points and the consequential loss of valuable time for the school going children.

![Figure 9](image-url) — Long line of containers waiting to be filled with water on a community borehole (Uganda Radio Network –URN, 2008)

1.1.2.3. Distribution of Ground water in Uganda

There is an estimated more than 200,000 springs in Uganda and these serve as important water resources especially in the mountainous areas, central, western and south western regions of the country (DWD, 1994). They serve mainly the rural and poor urban slum populations. In other areas with deep ground water aquifers (especially in the eastern, northern and northeastern areas of Uganda), boreholes are the most commonly used methods of extracting ground water. Protected dug wells have also been utilized in some areas though not common.

There are very huge variations in the total available ground water for the different regions in Uganda with some regions having very little or no water at all. There is also a seasonal component to the amount of ground water available in certain regions, especially in the
Northeast (mainly in the Karamoja region) and in some Eastern parts of the country, ground water extraction rates normally exceed recharge rates, resulting in the drying up of wells and boreholes (Garduño, 1999) and this causes major water shortages for most time of the year. On the other hand, the utilization of ground water is not well developed for municipal water supply systems in major cities and towns in Uganda. However, a small portion of urban dwellers especially those in poor urban slum areas, who cannot afford piped water connections by NWSC, utilize ground water mainly from springs (protected and unprotected) and shallow wells. In such areas, water supply and sanitation standards are typically poor as described in the next section.

![Maps of Uganda showing the distribution of sustainable ground water resources in Uganda and their Utilization for Domestic Water supply in Different regions (Tinimuguya, 2011)](image)

**Figure 10**—Maps of Uganda showing the distribution of sustainable ground water resources in Uganda and their Utilization for Domestic Water supply in Different regions (Tinimuguya, 2011)

A positive aspect is that; the current sustainable ground water utilization rate is still very low (<15% of the available ground water resources) and there is enough ground water in most parts of Uganda to meet future demands for domestic water supply (Tinimuguya, 2011). However, with the current rapidly increasing population [growth rate of 3.576% (UBOS, 2011)] in Uganda that has consequently led to increased encroachment on and degradation of water catchment areas mainly by settlement and agriculture, there is most likely going to be significant shortages in good quality ground water resources if proactive planning is not initiated soon.
1.1.3. Rain Water

1.1.3.1. Sources

1.1.3.1.1. Quantity and Utilization

Rain water is an effective source of drinking water throughout the world especially in countries that receive adequate amounts of rainfall annually (Ahmed et al., 2011). Rain water harvesting in Uganda provides a relatively safe source of drinking water supply to communities especially in rural areas though its utilization is still on a small scale. Rain water harvesting and utilization is currently being practiced in rural areas among the regions receiving reasonably adequate amount of rainfall. Uganda receives annual rainfall ranging from 500 mm in the Northeastern region to 2500 mm in Southwestern regions and the areas in Lake Victoria basin. Successful projects using rain water harvesting have been implemented in Southwestern Uganda mainly in Kigezi region (Byomuhangi, 2007), Central region of the country, and in a few Districts in Eastern Uganda (Water-Aid Uganda). Harvesting of rain water has also been implemented in many institutions (mainly rural primary schools and churches) in Uganda and these projects have recorded tremendous contribution towards the control of diarrheal diseases among the school going children.

1.1.3.1.2. Quality Issues

Consuming untreated rain water poses potential public health risks from microbial pathogens especially when water is not hygienically handled or where the collection surfaces and storage tanks are not kept in clean conditions. Several case control studies established potential links between gastroenteritis and consumption of untreated rain water (Ahmed et al., 2011). However, rain water usually has a lower level of contaminants if the atmosphere is kept clean, though the quality normally tends to deteriorate throughout the process of; harvesting/collection, storage and use. The rain water collection surfaces and tanks are usually potential sources of rain water contamination since all the dirt carried by wind, fecal matter from birds and animals and any other environmental contaminants can collect there and thus pose potential public health risks if such water is consumed. Poor personal hygiene and sanitation practices have also been implicated in contamination of rain water in storage tanks and during usage. Rain water contamination and the risks involved can be reduced by having properly designed rain water harvesting systems with clean collection surfaces, covered
storage tanks and appropriate treatment of water before consumption, in addition to good hygiene and sanitary practices during use at household level (WHO, 2008).

The existence of pathogenic microbes in Uganda’s rain water is generally lower than in the surface water sources. However, higher microbial contamination of collected rain water as indicated by E. coli and thermo–tolerant coliforms is common especially in water collected within the first 5–10 minutes of rainfall due to contaminated collection surfaces, but the level of contamination usually decreases as it continues to rain. With incessant rainfall episodes, significant reductions in microbial contamination are usually observed since the collection surfaces get frequently washed with fresh rain water. The microbial quality of rain water should be considered less than that expected for potable water.

Under normal environmental conditions, rain water is slightly acidic and has a low concentration of dissolved minerals. Therefore it can dissolve metals and other impurities from materials of the collection surfaces and storage tanks. In Uganda, the most commonly used rain water collection surfaces are buildings roofs made of corrugated iron sheets and the water tanks are normally made of plastic or vessels made of cement and sand reinforced with iron mesh (ferro-cement tanks). If there is no atmospheric pollution, iron is expected to be highest in concentration where rusty roofs are used to collect rain water.

1.1.3.2. Treatment processes and Storage
1.1.3.2.1. Treatment of rain water
   1.1.3.2.1.1. Filtration
Filtration of rain water is at the inlet point of the collection/storage tank. The collection tanks are always fitted with a water filtering mesh which helps to remove the organic debris mainly dead plant leaves and any other large particles that collect at the catchment surfaces and are carried with collected rain water before it enters the tank. In most cases, the rain water collection system is designed in such a way that; the first 5-10 minutes flash of rain water is not collected so as to get rid of most materials and dirt collected on the water collection surface. This reduces on the amount of debris reaching the filter.
Filtration using a mesh as applied in rain water systems, doesn’t remove the finer suspended particles that may come from dust collected at catchment surfaces.

Figure 11—Rain water Harvesting Tank showing a filter basin at the opening (Dai and Vince, 2005)

1.1.3.2.1.2. Disinfection
The methods of rain water disinfection practiced in Uganda are the same as for ground water.

1.1.3.2.2. Rain water Storage
Institutional rain water tanks, which are mostly made of plastic material (PVC), steel material, and sometimes brick masonry tanks with capacity/volume ranging from 15–100 m$^3$ have been installed at several school and church buildings to collect and store rain water that is used to serve these particular institutions and the neighboring communities (Byomuhangi, 2007).

Figure 12—Communal Rain water Harvesting and Storage Tanks (ugandanwaterproject.com; Water–Aid, 2007)

However, there are several issues concerning equitable distribution of the collected rain water amongst the beneficiaries as well as maintenance, sustainability of these facilities
at community level. As a result, the household level rain water harvesting facilities (jar and ferro-cement tanks) are used for some communities. The Rain water Jar is a low cost tank with a capacity of 420 liters (0.42 m$^3$) and typically serves a household with six people and less; the Ferro-cement Tank has a capacity of 4,000 liters (4.0 m$^3$) and a higher initial cost but provides a better solution for rain water harvesting and storage than the ‘jar’. However, some individuals who can afford large size tanks and have larger collection surfaces install large institutional size tanks on their households.

![Figure 13—Household Rain water Harvesting and Storage facilities/Tanks (Byomuhangi, 2007; Water-Aid Uganda, 2007)](http://ugandanwaterproject.com/t/rain-water-harvesting) accessed Feb, 2012

1.1.3.3. Distribution of Rain water in Uganda
Rain water distribution in Uganda varies by region and season. Rain water harvesting works best for those regions receiving fairly regular rainfall throughout the year. In Uganda, the amount of rainfall received per region varies significantly with some regions (e.g. Northeastern Uganda – Karamoja) receiving as low as 500 mm of rainfall annually and other areas (such the L. Victoria and its basin) receiving as high as 2500 mm of rain annually. As such the harvesting and utilization of rain water has only been possibly implemented mostly in the central, western and eastern regions of the country. Harvesting of rain water in the northern and northeaster Uganda has not been given enough attention due to issue of long dry spells. In particular, Northeastern Uganda is semi-arid and receives very little rainfall throughout the year and thus it isn’t feasible to invest in rain water collection in such a region. Generally for the regions receiving a fair amount of rainfall throughout the year in Uganda (central, western, southwestern, eastern and regions), the wet (rainy) seasons are normally March–May and October–November; dry
seasons are usually December–February and June–August. However, with current global climatic change, the seasons have been frequently changing, making it rather hard to accurately predict the rain and dry seasons in the country.

Figure 14—Map of Uganda showing the different Regions/Provinces
(http://www.medicalecology.org/diseases/westnile/Uganda_provi.gif
accessed March, 2012)
1.1.4. Government Regulation on Water Supply in Uganda

The Ministry of Water and Environment (MWE) regulates and coordinates the water sector and is the lead agency that formulates national water and sanitation policy. The Directorate of Water Development (DWD) under the MWE acts as the executive arm and provides support to local governments and other service providers (ADF, 2005). DWD is also expected to monitor the quality of drinking water provided by NWSC. However, in practice NWSC monitors its drinking water quality internally without any complementary external monitoring (Schwartz, 2006). NWSC’s internal Quality Control Department examines whether the supplied water complies with the national standards for drinking water, which in turn follow the WHO drinking water guidelines (NWSC, 2008).

The NWSC proposes water tariffs but they must be approved first by MWE before taking effect. The operations of NWSC are regulated through a performance contract with the national government. MWE’s Performance Review Committee (PRC) reviews the performance of NWSC according to the contract. However, this PRC is partly financed by the NWSC, which hinders its full independence (Mugisha and Berg, 2008). NWSC regulates its local branch offices through internal contracts that are monitored by its internal monitoring and regulation department.

There are laws and regulations relevant to the management and utilization of the water resources in Uganda. These laws govern the use of lake resources and other water catchment areas. However, there are several gaps in the enforcement of some of these laws due to several government bureaucracies and political influences.

The laws define the rights and duties of all the stakeholders and the guidelines for management of water resources. Policy outlines the principles of action to be followed in developing the rules of practice and gives direction to the activities in the sector. Below is the information on legal, policy and institutional frameworks within which the control and management of activities in the sector of water and sanitation in Uganda are steered:
1.1.4.1. Legal Context

1.1.4.1.1. The Constitution of the Republic of Uganda, 1995

The Constitution provides the state objectives and an outline for the general principles of state policies. It requires that; the state shall uphold sustainable development and public awareness of the requirement to manage land, air and water in a balanced and sustainable state for the current and prospective generations. This includes the protection and preservation of water sources, and environment and allows for the measures to promote good water management to prevent damage to air, land, and water resources resulting from pollution and any other causes. It also states that all Ugandans have the right to a clean and healthy environment, and expects every citizen to fulfill their part in ensuring this. The aspect of clean and healthy environment can’t be achieved without safe drinking water, because after all, “what is a healthy environment without clean drinking water!”

There are several standards and policies for managing water quality in Uganda which include: National Standards for Drinking Water, 1994; World Health Organization (WHO) Guidelines, 1998 which pay more attention to specific meteorological conditions and the associated water use practices; the National Effluent Standards for discharge of waste water into the environment; and the Provisional Water Quality Guidelines, 1996 for untreated rural water supplies.

**Table 1:** The 1994 Uganda’s National Standards for Drinking Water and the 1998 WHO and U.S. EPA Guidelines for Drinking Water Quality.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>15 TCU</td>
<td>15 Color Units</td>
<td>15 Color Units</td>
</tr>
<tr>
<td>Odor</td>
<td>—</td>
<td>3 Threshold Odor Number</td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td>≤ 5 NTU</td>
<td>≤ 5 NTU</td>
<td>≤ 5 NTU</td>
</tr>
<tr>
<td>Chlorine</td>
<td>—</td>
<td>4 mg L⁻¹ as Cl₂</td>
<td>0.5 mg L⁻¹</td>
</tr>
<tr>
<td>pH</td>
<td>—</td>
<td>6.5 – 8.5</td>
<td></td>
</tr>
<tr>
<td>TDS</td>
<td>1000 mg L⁻¹</td>
<td>500 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td>250 mg L⁻¹</td>
<td>250 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Fluoride</td>
<td>1.5 mg L⁻¹</td>
<td>4.0 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td>50 mg L⁻¹ as NO₃⁻</td>
<td>10 as N₂/44.44 as NO₃⁻</td>
<td></td>
</tr>
<tr>
<td>Nitrite</td>
<td>3 mg L⁻¹</td>
<td>1 mg L⁻¹ as N₂</td>
<td></td>
</tr>
<tr>
<td>Sulfate</td>
<td>250 mg L⁻¹</td>
<td>250 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower Limit</td>
<td>Upper Limit</td>
<td>WHO Limit</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------</td>
<td>-------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Iron</td>
<td>0.3 mg L⁻¹</td>
<td>0.3 mg L⁻¹</td>
<td>0.3 mg L⁻¹</td>
</tr>
<tr>
<td>Ammonia</td>
<td>1.5 mg L⁻¹</td>
<td>Zero</td>
<td>1.5 mg L⁻¹</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.2 mg L⁻¹</td>
<td>0.05 – 0.2 mg L⁻¹</td>
<td>0.05 mg L⁻¹</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0.01 mg L⁻¹</td>
<td>0.01 mg L⁻¹</td>
<td>0.01 mg L⁻¹</td>
</tr>
<tr>
<td>Bromate</td>
<td>0.025 mg L⁻¹</td>
<td>Zero</td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.003 mg L⁻¹</td>
<td>0.005 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Chromium</td>
<td>0.05 mg L⁻¹</td>
<td>0.1 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>0.01 mg L⁻¹</td>
<td>0.015 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>0.5 mg L⁻¹</td>
<td>0.05 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>0.001 mg L⁻¹</td>
<td>0.002 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Selenium</td>
<td>0.01 mg L⁻¹</td>
<td>0.05 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>200 mg L⁻¹</td>
<td>Zero</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>3 mg L⁻¹</td>
<td>5 mg L⁻¹ SS</td>
<td></td>
</tr>
<tr>
<td>THMs</td>
<td>–</td>
<td>0.08 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>HAAs</td>
<td>–</td>
<td>0.06 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Virus</td>
<td>–</td>
<td>0 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Cryptosporidium</td>
<td>–</td>
<td>0 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Giardia</td>
<td>–</td>
<td>0 mg L⁻¹</td>
<td></td>
</tr>
<tr>
<td>Total coliforms</td>
<td>0 Counts/100 ml</td>
<td>0 Counts/100 ml</td>
<td>0 Counts/100 ml</td>
</tr>
</tbody>
</table>

**Note:** The table includes just a few of WHO’s and U.S. EPA drinking water guidelines. Uganda has the capacity to regulate and monitor only a few standards as listed in the table, due to a limitation on infrastructure, mainly laboratory space and equipment. Most of the activities in Uganda’s water sector especially the provision of potable drinking water are said to be in line with the WHO standards/guidelines but one cannot be completely sure since there are no systems in place to monitor most of the standards.

The Water Act, 2000 and the accompanying regulations (such as; the Water Resources Regulations, 1998; the Waste Discharge Regulations, 1998; the Water Supply Regulations, 1999; and the Sewerage Regulations, 1999) list a number of activities that must be implemented so as to protect, develop and sustain water sources, as guided by the objectives in the 1995 Uganda’s Constitution. As such, the licensing of water abstraction and waste discharge are based on: the Water Act, 2000 (chapter 152); The National Environment Act, 2000 (chapter 153); and the accompanying regulations mentioned above. The legislative context for the protection of water sources, and water quality testing and monitoring, is also covered by the Water Act, 2000 and is in turn guided by National Water policy (NWP), 1999.
At implementation level, all the activities that are known to significantly impact water quality are controlled through a range of endorsements, which are either managed directly by the Directorate of Water Development (DWD), or in partnership with National Environmental Management Authority (NEMA). The National Environment Act, 2000 (chapter 150); and the Waste Management Regulations, 1999, cover the concerns of issuing of waste (solid and liquid) disposal site permits so as to protect against contamination of water sources (both ground and surface water sources). The Water Act, 2000 (chapter 152) provides for self-regulation of the permit holders.

The National Environment Act, 2000 (chapter 150) and the NWP, 1999 provide the recommendations for approval of Environmental Impact Assessments (EIAs) to ascertain the effect of some environmental activities on the quality of drinking water.

1.1.4.1.2. The Water Statute, 1995
The Water Statute, 1995 is the principle law for the water sector and incorporates water resources management plus water and sanitation legislation. The statute provides the agenda for use, protection and management of water resources; as well as the constitution of water and sewerage facilities so as to facilitate the devolution of water and sewerage activities.

The Uganda Water Statute of 1995 basically sets out four main objectives as indicated below:

a. Promote a balanced management and use of Uganda’s water by:

- Progressive introduction and application of suitable standards and methods for the protection and management of water resources;
- Coordination and allocation of duties among Ministers and public authorities for the protection and management of water resources;
- Coordination of all activities that may impact water quality, and management of water resources;

b. Promote the supply of clean sufficient water for domestic use to all folks in the country;
c. Regulate pollution and promote safe storage, treatment, discharge and disposal of waste which may otherwise pollute water or harm the environment and human health if not well handled;

d. Allow for organized advancement and usage of water resources in ways which minimize detrimental effects to the environment and human health.

1.1.4.1.3. The Local Governments Act, 1997
The Local Governments Act, 1997 specifies the responsibilities of the central government, District Councils, Urban Councils and those to be decentralized by the District Council to lower Government Councils. This act/deed defines the roles of different levels of government in the provision and management of water and sanitation related activities. This is done in conformity with the Constitution and it builds on the Decentralization Act, 1995.

1.1.4.1.4. The National Environment Statute, 1995
The National Environment Statute, 1995 which builds on the National Environment Policy, was formulated with a major aim of providing sustainable environmental management. The statute empowers National Environmental Management Authority (NEMA) to act as an overall regulatory body for issuing guidelines, measures and criteria for sustainable management and protection of environment and all natural resources. As lead agency in the water sector, the DWD has a collective duty with NEMA for ensuring; water quality standards, standards for discharge of effluent into water, limits on the uses of water bodies, management of riverbanks and lake shores, and restriction on the use and management of wetlands. There are fines and strong punishments that include; imprisonment, demolition of buildings constructed in wetlands, etc. that are imposed on those folks who act in contravention of the law regarding protection and preservation of these natural resources.

1.1.4.1.5. The Public Health Act, 1964
The Public Health Act, 1964, Chapter 269 aims to consolidate the law regarding the preservation of Public Health. It lays out the framework for regulating the pollution of the environment (air, water, etc.) to injurious limits which can be risky to the human health.
1.1.4.1.6. Water Resources Regulations and Waste Water Discharge Regulation, 1998

The Water Resources Regulations, 1998 and Waste Water Discharge Regulation, 1998; prescribe the threshold and procedure for applications to construct any works, use water or discharge waste under the Water Statute 1995. The Water Statute, 1995, provides for the establishment of regulations for controlling water abstraction and wastewater discharge through use of permits. These controls also ensure that water is not treated as a free commodity but as goods with a monetary value. That way, people handle their drinking water with a lot of caution.

1.1.4.1.7. Land Act

The Constitution of the Republic of Uganda, 1995 and Land Act, 1998 describe the various land tenure systems in Uganda. All the land is entrusted to citizens of Uganda to be owned and utilized in accordance with; Customary, Mailo, Freehold, and Leasehold land tenure systems. Both the Government and private owners of land can set up and manage facilities on land they occupy or own according to the requirements of the given tenure system. Land tenure issues are critical to the development of water infrastructure. Any location of a water supply project must respect the proprietary rights of the landowner or occupier as protected by the Constitution of the Republic of Uganda, 1995 and the Land Act. 1998. The Act allows for reasonable use by the occupier/owner of a piece of land, of water for domestic and small-scale agricultural purposes.

1.1.4.2. Policy

The policy trend for water quality management is steered towards the protection of public health, improved human resources, ecosystem integrity, and socio economic development.

The overall government policy objectives for water resources management and utilization related to drinking water supply are as follows:

a. Ensure full participation of all stakeholders in an integrated and sustainable management and development of Uganda’s water resources, so as to secure and provide water of adequate quantity and quality for all socio and economic needs of the current and future generations (NWP, 1999).
b. To provide sustainable provision of safe water within easy reach and hygienic sanitation facilities based on management obligation and ownership by the users, to 77% and 100% of the rural and urban populations respectively by the year 2015 with an 80-90% effective use and functionality of facilities. The MDGs, aimed at halving the percentage of people without access to safe water by 2015 in Uganda.

1.1.4.2.1. Poverty Eradication Action Plan (PEAP)
Poverty eradication remains the central objective of the Government of Uganda. The Poverty Eradication Action Plan (PEAP) provides an over-arching agenda of guiding public action in order to eradicate poverty and the water and sanitation sector programs are thought to address some of the objectives of PEAP. In the revised PEAP (2004) water and sanitation fall under 2 of the 5 pillars: Pillar 2 – Enhancing production, competitiveness and incomes; and Pillar 5 – Human development.

1.1.4.2.2. The National Water Policy, 1999
The 1999 National Water Policy (NWP) elaborates on the Uganda’s Water Statute of 1995 and provides the overall policy context for the water sector. It promotes an integrated approach for management of water resources in the most sustainable and beneficial ways. It accentuates a continuous acknowledgment of water as a common social and economic good, whose allocation for domestic use should be given first priority. The NWP was established under 2 categories: Water Resources Management; and Water Development and Use. It sets out: the regulatory principles; strategies; management functions & structure; roles of the private sector & NGOs; as well as data and information with respect to water resources. The Water Policy also sets out guiding principles of Water Production.

1.1.4.2.3. The National Health Policy, 1999
The National Health Policy (NHP), 1999 restates that; sanitation is a mandate of the Ministry of Health (MoH), and that; the fight against poor sanitation has to be strengthened and upheld in order to consolidate and improve on the gains made in this area. It addresses malaria, HIV/AIDS, tuberculosis (TB) and diarrhea as the major disease burdens. The government puts a greater emphasis on improving sanitation and hygiene
especially in rural and urban slum areas where access to safe water and sanitation coverage is low.

1.1.4.2.4. The Environmental Health Policy, 2005
The Environmental Health Policy, 2005 establishes the environmental health priorities (clean/safe drinking water, housing, clean air, etc.) of the government and provides a framework for the development of services and programs at national and local levels. The goal of the Policy is the attainment of a clean and healthy living environment for all citizens in both rural and urban areas.

1.1.4.2.5. The National Gender Policy, 1999
The National Gender Policy, 1999: recognizes women and children as the major carriers and users of water; and encourages women to play a major role in decision making concerning water and sanitation activities. It lays down the importance of gender responsiveness in terms of planning, application and management of water and sanitation initiatives. Based on this policy, the level of women involvement in decision-making has been nationally established and is valued at all levels.

1.1.4.3. Institutional Framework
1.1.4.3.1. Sector-Wide Approach to Planning (SWAP), 2002
The water and sanitation officials use the sector-wide planning approach to support its policy and expenditure programs. The rural water and sanitation sub-sector is the most advanced in terms of application of SWAP. The water and sanitation sector is divided into four sub-sectors that perform different activities within the sector according to the Decentralization Act, 1995;

1. The Water Resources Management (WRM) sub-sector; concerned with the sustainable management of Uganda’s water resources so as to deliver adequate and quality drinking water for the current and prospective generations.
2. The Rural Water Supply and Sanitation (RWSS) sub-sector; encompasses the provision and upkeep of adequate supply of drinking water for people living in rural areas. The Sanitation aspect deals with hygiene and sanitation education plus campaigns in rural communities and schools.
3. The Urban Water Supply and Sanitation (UWSS) sub-sector; includes services for human consumption, industrial use, and other uses to urban areas (centers with population > 5,000 people). There are 43 large and 106 small towns across the country. Large towns’ drinking water is supplied by NWSC under a performance contract with the central Government and the small towns are managed by water authorities.

4. The Water for Production (WFP) sub-sector; basically addresses the issues of water for agricultural production (irrigation, livestock, fish farming, etc.). The Ministry of Agriculture, Animal Industry and Fisheries (MAAIF); and the DWD/MWE and are responsible for WFP

1.1.4.3.2. Institutional Roles and Duties
There are several institutions/stakeholders involved in water sector. The Ministry of Water and Environment (MWE)/DWD is the lead agency responsible for liaising with other stakeholders; The NWSC provides water and sewage services in major urban centers; The Ministry of Health (MoH) is responsible for formulation and implementation of policy to promote sanitation and hygiene. The Environmental Health Division (EHD) is the main division of MoH responsible for supporting environmental health at different levels; The Ministry of Education and Sports (MoES) provides sanitation and hygiene promotion in primary schools. MoES works to ensure that schools have all the essential sanitation facilities and also provides hygiene education to the pupils; Local Governments (Districts, Towns, and Sub-counties) are responsible for the provision and management of rural water services with help from the DWD/MWE.

1.1.4.3.3. District Roles and Duties
The implementation of sector activities requires full participation and cooperation between all major stakeholders. The District Water Office (DWO) is the lead office for water and sanitation sector activities at local Government level, takes the lead in the implementation of all the water and sanitation activities at district level, and is responsible for initiation and follow-up of capacity building, as well as ensuring operation and maintenance of water and sanitation facilities by water user groups (WUGs); the District Directorate of Health Services (DDHI) ensures coordination with the DWO in implementation of sanitation activities and hygiene education promotion; the
District Directorate of Community Based Services (DDCBS) works together with the DWO on matters related to community sensitization and mobilization before and after construction of water and sanitation facilities to ensure sustainability of these projects; the District Education Officer liaises with the District Directorate of Health Services (DDHS) and DWO in planning and implementation of sanitation and hygiene education in schools and institutions; the Chief Administrative Officer (CAO) as the accounting officer for all District funds, has a duty of general management and approval of the district water and sanitation activities; the District Planner participates in the planning of water and sanitation activities in the Local Governments. The list of stakeholders at the district level is extensive.
2.0. Chapter Two
2.1. Review of the drinking water programs in other countries (the U.S., Latin America and Caribbean)

   a) The United States (U.S.):
   2.1.1. Surface water
   2.1.1.1. Sources

   Naturally, Surface water is replenished through precipitation (rain & snow fall), and lost through evaporation and soil infiltration into ground water supplies. The United States Environmental Protection Agency (U.S. EPA) estimates that, 68% of the public water system users received their water from a surface water source, such as a lake (U.S. EPA, 2008). Thus, Surface water continues to be a major source of freshwater in the U.S. and is used for a wide range of applications mainly agriculture and public water supply. In 2005, [80% – 328 billion gallons/day (Bgal/d) or 1.24162 billion m³/day] of the total water [about 410 Bgal/d or 1.552 billion m³/day –fresh and saline] used per day (for; thermoelectric power, public water supply, irrigation, aquaculture, mining, and industrial purposes), came from Surface water sources such as; rivers, streams, creeks, lakes, and etc. (Kenny et al., 2009). Ground water accounted for the remaining 20%. More than 85% of total water used was fresh-water. Saline water was mainly applied in thermoelectric-power industry, and a small portion of it for industrial and mining applications. Approximately 77% of the total freshwater used in the United States in 2005 was Surface water and the remaining 23%, ground water (USGS, Mar. 2012). Generally, the use of surface water for different applications in U.S. has been on a steady increase since the 1950s as demonstrated in the graph below.

![Graph showing Surface water withdrawals and population growth from 1950 to 2005](image-url)
In 2005, about 52.7% of the total fresh surface water withdrawals were used in thermoelectric-power industry. However, water used for this purpose is mostly reverted to its source and thus no significant reductions in water levels at the resource with this water application. For this particular reason, agricultural application (majorly irrigation) taking up about 28% of all fresh surface water followed by public water supply and industrial uses, are considered the most significant applications in terms of surface water resource depletion, since the water used doesn’t often return to the source.

2.1.1.2. Quality Issues

Water quality in the United States especially drinking water remains a source major concern regarding pollutants in some areas. The quality of surface water has to constantly remain in check since a large percentage of the fresh-water supplies in the U.S. mainly come from surface water sources. Drinking water quality in the U.S. is regulated by federal and state laws and codes, which set maximum contaminant levels for a number of pollutants, determine various minimum operational requirements and require utilities to publish consumer confidence reports that tell people where their water comes from and what’s in it (U.S. EPA, 2011).

Surface water being open to the environment is much more prone to pollution and contamination by chemicals and heavy metals (such as; Pd, Cd, Hg, As, etc.) from industrial effluents/wastes; pesticides & herbicides; nutrient fertilizers (phosphates and
nitrates) applied in agriculture; and a wide range of pathogenic and nonpathogenic microbial contaminants from animal and human excreta. Surface runoffs potentially affect the quality of the water from surface water sources. In the U.S. the common contaminants in surface water are metals, organic chemicals (pesticides and herbicides) and nitrates from a range of industrial and agricultural applications. Nitrates are essential plant nutrients, but excessive levels cause significant water quality hitches. In combination with phosphorus, nitrates can accelerate eutrophication of surface water sources causing severe water quality issues. Nitrate contamination of surface water has been noted in areas with a lot of livestock production and where nitrates are applied as soil fertilizers to boost production of food and cash crops such as; corn, cotton, and vegetables e.g. in most Western States U.S. (Mueller and Helsel, 1996; Devinder K. Bhumbla). Nitrate contamination of water (surface water and shallow ground water) has also been discussed under “ground water section” below.

For several decades, pesticides have been widespread in surface water sources in the U.S. though at low concentrations. The levels of pesticide in Surface water sources in the U.S. follow specific seasonal trends resulting from the timing of pesticide applications and surface runoff conditions. In some rivers and streams, some pesticides are in high concentrations seasonally though the annual average levels are usually low and seldom exceed regulatory standards for drinking water (USGS, 2007). Hundreds of pesticides that have been used in the United States are detected in surface waters in all regions across U.S. Detection levels for herbicides and insecticides are proportional with their application for agricultural production. Generally, herbicides (such as; atrazine, cyanazine, simazine, metolachlor, alachlor and 2, 4–D) have been detected in surface water more frequently than insecticides. This is consistent with the greater herbicide application in agriculture currently. Pesticides have not been detectable of recent in most surface water in U.S. mainly due to low application. In earlier studies conducted in the 1990s, pesticides were detected in some regions of U.S. e.g. in surface waters from Mississippi River basin and other parts of the Midwest due to the wide spread application at the time (USGS, 2007).
2.1.1.2. Treatment processes and Storage
2.1.1.2.1. Surface water Treatment
2.1.1.2.1.1. Filtration
All surface waters have the potential to carry pathogenic microbes and must be disinfected to make it potable. Typically, water will not be completely/adequacy disinfected in the presence of turbidity (suspended organic and inorganic particles). Thus it is a necessary step, to first remove these suspended solids causing the turbidity in water before any disinfection (especially chemical disinfection) is done. This is achieved by a series of treatment processes that usually includes; coagulation, flocculation, sedimentation, and then filtration.

The Surface Water Treatment Rule under the 1986 Safe Drinking Water Act (SDWA) Amendments requires the water supply systems using surface water and ground water under the direct influence of surface water, to filter their water supplies. Filtration of water in the U.S. is predominantly by slow sand filtration which is mostly used in public water supply plants. Other systems that treat surface water with high organic loads use activated carbon filters to achieve maximum removal of organics from the water.

2.1.1.2.1.2. Disinfection
Once the water is filtered, it can satisfactorily be disinfected to eliminate all the pathogenic microbes that will have survived all the prior water treatment processes. Disinfection doesn’t render the water completely sterile but it makes it safe for drinking in terms of microbial quality. Most water treatment plants in the U.S. rely primarily on chlorine for disinfection. Some utilities use ozone, chlorine dioxide, chloramines, or a combination of chemicals added at different points during treatment. The choice of the disinfection method to use usually depends on the quality of raw water and the associated costs of using a particular disinfectant.

2.1.1.2.2. Storage
The storage of surface water in the U.S. is by use of ground water tanks or the overhead water storage tanks. The water storage tanks are utilized for both the water treatment plants and at household level to ensure a continuous supply of drinking water. The water treatment plants usually have storage tanks, where treated water is stored before it is pumped into the distribution system for public supplies. These tanks serve two major
purposes, the primary one being water storage and the other as monitoring points for compliance of the treated water with established water quality standards.

2.1.1.3. Distribution
The relative amount of Surface water resources per state corresponds to the observed withdrawals/usage in time space. States with high amount of surface water resources have high withdrawals. Withdrawals also correspond to the extent of agricultural production and other water applications in the respective states. About 30% of all fresh Surface water withdrawals in 2005 occurred in five States (California, Idaho, and Colorado, Texas and Illinois). In California, Idaho, and Colorado, most of the withdrawals were for irrigation and in Texas and Illinois; withdrawals were mainly for thermoelectric power generation (USGS, Mar. 2012).

Figure 17—Map of U.S. Showing Surface water Withdrawals by State in 2005 & the Pie Chart shows the States that used the most Surface water as a Percentage of the total Surface water use for U.S. (USGS, Mar. 2012)
2.1.2. Ground water

2.1.2.1. Sources

2.1.2.1.1. Quantity and Utilization

The U.S. uses about 83.3 billion gallons per day [or 315.325 million m³/day] of ground water (http://www.waterandhealth.org/newsletter/private_wells.html). Estimates of water use in the U.S. indicate that, approximately 410 Bgal/d or 1.552 billion m³/day of which 19.41% (79.6 Bgal/day or 0.30132 billion m³/day) was fresh ground water, were withdrawn in 2005 for all categories of water use (Kenny et al., 2009; USGS, December 2011). There are about 1400 ground water sites in the US with California, Florida, Missouri, New York, Virginia and Pennsylvania contributing the highest numbers to the overall ground water sites in US (USGS, November 2011). Domestic self-supplied water especially in country side of US is almost exclusively ground water. This water also serves the purpose of livestock production. The proportion of the U.S. population obtaining drinking water from public suppliers increased from 62% in 1950 to 86% in 2005 (Kenny et al., 2009). Generally, the amount of ground water used annually in the US has been on a steady increase since 1950 as demonstrated in the Figure 18.

![Figure 18—Bar chart showing Ground water use in the US from 1950–2005 and Pie Charts Showing the Proportions of Ground water (Fresh and Saline) used (USGS, Dec. 2011)](image)

Ground water utilization for domestic purposes and other applications (such as; agriculture and industrial uses) in the U.S. has increased over years due to an increase in population growth rates, industrialization and the consequential pollution of Surface water sources. The deteriorating surface water quality has been one of the reasons for the augmented exploitation of ground water resources in most countries worldwide.
Most fresh ground water withdrawals (68%) are used for irrigation purposes and public water supplies (19%) as shown in Figure 19 below. More than 98% of self-supplied domestic water came from ground water withdrawals (USGS, December 2011).

![Figure 19 — Bar chart showing Ground water withdrawals/use by category of use in the U.S. by year 2005 (USGS, December 2011)](image)

### 2.1.2.1.2. Quality Issues

The quality of ground water in the US and indeed all the other countries worldwide remains un-refutably better than for surface water. As a result, ground water has been a preferred source of drinking water due to the general perception that it has higher quality; less susceptible to pollution, and requires less intensive and cheaper treatment than other water types. However, with increasing population and industrialization activities, there has been tremendous pollution of available fresh ground water sources with waterborne pathogenic microbes as well as several chemicals and heavy metals (such as arsenic, lead, etc.) from industrial and agricultural wastes that are released into the environment end up percolating through the soils, finally gaining access to the ground water aquifers. Ground water is also susceptible to natural pollution by iron, manganese, and arsenic naturally found in soil and ground water holding rock formations. The United States Environmental Protection Agency (U.S. EPA) regulates the occurrence of Iron (Fe), Manganese (Mn), Arsenic (As), and Lead (Pb) and maximum contamination limits (MCLs) of: Fe– 0.3 milligrams per liter (mg L\(^{-1}\)); Mn– 0.05 mg L\(^{-1}\) [NYS regulates Fe & Mn individually at MCL of 0.3 mg L\(^{-1}\), and collectively at 0.5 mg L\(^{-1}\)]; As– 0.01 mg L\(^{-1}\) and Pb– 0.015 mg L\(^{-1}\) in the municipal water supplies.

Arsenic occurs naturally in rocks and soil, water, air, and plants and animals and is regulated at a MCL of 10 ppb (0.01 mg L\(^{-1}\)) in water supplies since January 23, 2006.
U.S. EPA, 2001). Naturally occurring arsenic in ground water is found in two forms: arsenate [As(V)] and arsenite [As(III)], arsenate is more common. High arsenic levels in ground water are common in certain regions of the U.S. (e.g. higher arsenic concentrations are more frequently observed in ground water from the western part of US than the eastern U.S. states). Investigations of arsenic concentrations in ground water from several states in the U.S. over the past decade indicate that; arsenic levels more than 10 micrograms per liter (µg L⁻¹) are more common than formerly measured (Welch et al., 2000) and iron oxide is suspected to be the most common cause of the occurrence of arsenic at this level in ground water especially from the western U.S. due to the presence of felsic volcanic rocks and alkaline aquifers in addition to organic carbon from both natural and anthropogenic sources. Iron oxide is known to react with organic carbon and interact with alkaline ground water causing the release of arsenic in such ground water. Occurrence of arsenic in U.S. ground water has also been linked to sulfide minerals which act as both a source and sink for arsenic. For example, during the coal mining; the pyrite (iron sulfide) in the mine drainage contains a bulk of arsenic which can easily leach into the soil and access the ground water aquifers. The high concentrations of arsenic in ground water from the Warrior Basin in Alabama were linked to coal mining (Goldhaber et al. 1997) because the pyrite in most coal usually contains arsenic (Coleman and Bragg 1990) and is thus thought to be the most likely source of arsenic in coal mine drainage. Arsenic has also been measured in ground water from other areas in the U.S. where coal mining is not apparent such as the Appalachian highlands and the Atlantic plain though the concentrations are significantly lower than the coal mining areas (Welch et al., 2000).

Pesticides also continue to be detected in relatively high levels in both shallow ground water and surface water sources in the U.S. although higher concentrations are more in surface water. The use of pesticides in the U.S. has remained steadily high at about 1 billion pounds/year with 70–80% of total pesticide in the U.S. being applied for agricultural production as herbicides and insecticides. Particularly the application of persistent pesticides in the U.S. declined over years but the use of less persistent insecticides increased since, due to increasing demands for agricultural production as a result of population increase (USGS; Sources of nutrients and pesticides).
High nitrate (as nitrogen) levels have also been measured in shallow ground water in the U.S. particularly in areas with well-drained soils and have also been linked to intensive agricultural production of food and cash crops such as; corn, cotton, and vegetables (Mueller and Helsel, 1996). The areas using ground water from deep aquifer formations, nitrate contamination of water at the source is not an issue. The U.S. Environmental Protection Agency (U.S. EPA) regulates nitrate in drinking-water at a standard level of 10 mg L$^{-1}$ nitrate as nitrogen (U.S. EPA, 1995). In absence of any contamination, nitrate concentrations in natural ground waters are usually less than 2 mg L$^{-1}$ (Mueller et al., 1995). Exposure to high nitrate levels results in blue baby’s syndrome also known as Methemoglobinemia.

The regulation (control and monitoring) of ground water quality for the self-supplied households is not covered by the U.S. EPA drinking water guidelines. However, the private well owners are supposed to monitor bacteriological quality of their water and report to their respective water districts annually. It is therefore exclusively the responsibility of the private well-owners to ensure that they have quality drinking ground water from their water source. Ground water chemical and bacteriological quality measurements are only taken if the people complain about the quality of their water or if a certain epidemic outbreak or high blood levels of a certain heavy metal such as lead has been detected in the local population and has been suspected to be linked the water source used. Water quality measurements/determinations are also usually required before new owners occupy a given residence using a private ground water source.
2.1.2.2. Treatment processes and Storage
2.1.2.2.1. Ground water Treatment
2.1.2.2.1.1. Filtration

In the U.S. and other countries worldwide, the quality of drinking water remains an extremely vital issue to be addressed, as a result of continued population growth and strained water supplies. It is estimated that about 20% of the homes in the U.S. have some type of water filtration or purification system installed (Doug Pushard, 2012).

In public water supplies containing arsenic contamination, filtration has been used to remove the arsenic in water. Arsenic in ground water usually exists as arsenate which is easily removed by coagulation and then membrane filtration processes. Where arsenic exists as arsenite, it is oxidized first usually with H₂O₂ (hydrogen peroxide) to arsenate which can then be removed by coagulation and membrane filtration processes. Filtration has also been used to remove iron and manganese from ground water. In this case, the dissolved metals are first oxidized by exposure of the ground water to air in order to form precipitates which can then be filtered out of the water. In ground water, iron exists as ferrous iron (Fe²⁺) and manganese as manganous (Mn²⁺). These ions are soluble in water with relatively low oxygen concentrations that are typical of ground water. On exposure to air, Fe²⁺ is oxidized to insoluble brown precipitate of ferric iron (Fe³⁺) and Mn²⁺ to insoluble black precipitate of manganic manganese (Mn⁴⁺) which can be filtered out of the water.

Granular activated carbon (GAC) filters are also used in several states in the U.S. for the removal of any dissolved organic contaminants in ground water for both municipal water supply systems and household self-supplied water systems. GAC filters are far more effective than fine-sand filtration for the removal of organics in water. Under natural conditions, ground water will have little or no organic contaminants but may get contaminated due to the application of organic chemicals in agriculture and other industrial processes which end up gaining access to the available ground water sources.

2.1.2.2.1.2. Disinfection
Chlorination is major disinfection method applied for most water supply systems in the US and has played a critical role in protecting America’s drinking water supplies from
waterborne pathogens for many decades. Like any other water sources, ground water is not 100% pure as it always contains some dissolved minerals and many naturally occurring microorganisms that are either beneficial or pathogenic. As such, the U.S. EPA is particularly concerned about disinfection of ground water systems that are susceptible to fecal contamination since feces always contain disease-causing pathogens. In particular this led to the establishment of the Ground water Rule (GWR) in the Federal Register in year 2006 with the purpose of reducing the incidence of diseases associated with waterborne microbes in drinking water by providing increased protection against microbial pathogens in public water systems that use ground water sources; and those systems that mix surface- and ground water where ground water is added to the distribution system directly and supplied to the public without any prior treatment (U.S. EPA, 2006).

The U.S. EPA requires all public water supply systems to disinfect the water and regularly monitor the bacteriological quality. However, these standards don’t apply to wells used to serve a single household, which are commonly referred to as private wells. Thus, it is the sole responsibility of homeowners to protect, maintain and ensure supply of quality drinking water from their water sources. The quality of water from a particular ground water well is dependent on the location of that well with respect to points/sources of contamination, and extent to which the watershed is protected from excessive pollutant and sediment runoff. Disinfection of a private well is usually done using either sodium hypochlorite – NaOCl (Cl₂ bleach having 5–6% NaOCl) or calcium hypochlorite – Ca(OCl)₂ [65–70% Ca(OCl)₂], and may be carried out either by a ground water professional or by the well owner following instructions as available from state and local health departments.

Ultraviolet disinfection and ozone have also been utilized for drinking water disinfection especially in Water Treatment for Small Communities in the U.S. though the cost involved with the use of these techniques is still a limiting factor to their extensive application for water disinfection in the nation.
2.1.2.2. Storage
Storage of ground water at household level in the U.S. is by use of water storage tanks. Since most households who use ground water are self-supplied by private wells, the water is normally pumped from the well and stored into a reservoir where it is then channeled for different domestic applications. The public water treatment plant using ground water; also have storage tanks as discussed under the section for surface water storage above.

2.1.2.3. Distribution
Over 50% of fresh ground water withdrawals in the United States in 2005 occurred in six States (California, Texas, Nebraska, Arkansas, Idaho, and Florida,) and was mostly used for irrigation purposes except in Florida where 52% of the total fresh ground water withdrawals were used for public water supply (Kenny et al., 2009). Ground water utilization is somewhat dependent on its relative availability. For instance, the states that utilize ground water for irrigation basically have much more ground water and limited fresh surface water resources, because irrigation takes too much water compared to public potable water supplies.

Figure 21—Map of US by State Showing the amount of ground water usage per day and the Pie-chart showing which states use most of the ground water, 2005 (USGS, December 2011)

2.1.3. Rain water
The use/utilization of rain water is not apparent in the United States. As such, there are no records of rain water harvesting programs. Rain water quality and supply is not regulated by the U.S. EPA and Safe Drinking Water Act.
b) Latin America

South America is characterized by extremes: It is the Earth’s driest place (the Atacama Desert); one of the world’s dampest places (the Amazon Rainforest); and the world’s topmost commercially navigable lake (Lake Titicaca). With a total area of 6.8 million square miles, South America accounts for about 3.5% of the Earth’s surface. The continent ranks 4th in area and 5th in population size and is made up of 14 countries with Brazil being the largest.

2.1.1. Surface water

2.1.1.1. Sources

2.1.1.1.1. Quantity and Utilization

Latin America contains 33% of the world’s water resources and thus water is relatively abundant in most countries in Latin America (Abel Mejia, 2011). There are several fresh water rivers that navigate long distances across Latin America; these provide large amounts of water that can be utilized for agriculture and domestic water supplies. In South America Water accessibility is estimated at an average of about 28,000 cubic meters per capita per year, but there are significant seasonal variations in water availability and distribution. In Mexico, Central America, and the Caribbean, 49.3% of the total annual stream flow is from August – October and only 7.3% from February – April (Abel Mejia, 2011). Besides, there are those regions/countries with desert conditions where surface water is not available. Climatic conditions play a major role in the amount of surface water available for different countries in Latin America (refer to Figure 30—Climate zones).

The quantity and utilization of surface water in some Latin American countries (such as; Mexico, Venezuela, Honduras and others) is also affected by severe droughts that limits accessibility to portable water in such regions. Therefore, although much of Latin America has an abundance of water resources, it’s clear that some regions are performing poorly in terms of water accessibility generally.

2.1.1.1.2. Quality Issues

For most Latin American countries and in the Caribbean, the major contributor to Surface water pollution is sewage, a similar issue with Uganda’s water supplies. In Brazil for example, the 2000 National Survey of Sanitary Conditions, a nationwide water supply
survey for potable water accessibility and wastewater collection and treatment, indicated that more than 10% of the wastewater and sewage produced in urban areas wasn’t treated (Judicael et al., 2005). This is an indication that surface water sources are receiving untreated wastewater/sewage which greatly impacts both chemical and microbiological quality. Drinking water quality is managed at the state level, and there are wide variations in the quality of monitoring systems and surveys by different states with some states having excellent systems and other performing poorly (Secretariat for Water Resources, 2006). Generally, sewage is the major problem impacting water quality and consequently public health as well as economic development in large urban areas. The effects are even more pronounced in poor slums surrounding large cities in most Latin American countries.

São Paulo state in Brazil is considered to be having one of the best water quality monitoring and wastewater collection and treatment systems in the whole of Latin America. However, from one study assessing basic sanitary conditions (Leandro et al., 2004), high microbiological levels were recorded from both mainstream and 2 main tributary streams of one of the rivers in the state (Bairro da Serra River), indicating significant domestic sewage pollution. In addition, 91% of the households included in the study, were using simple septic tanks for sewage disposal and thus significantly polluting surface water and shallow ground water sources. The study also indicated big knowledge gaps among the local populations concerning the probable causes and control of waterborne diseases (Leandro et al., 2004). This means that surface water pollution in most Latin American countries is still a big issue.
Chemical contaminants including those sometimes described as persistent organic pollutants (POPs) such as pesticides from agricultural applications and PCBs have been found in surface water from Latin American countries. In Central America, there was still an increasing use of pesticides for cash-crop production by late 1990s (Kammerbauer and Moncada, 1998) and some organo-chlorine pesticides (such as endosulfan and lindane) were still permitted/legalized to be used in some Latin American countries by early 2000s (Allsopp and Erry, 2000) to mid-2000s, though in this work, the question remains as to whether these pesticides are still legally used/applied in the present times. [There is limited data on the levels of POPs in surface waters for most Latin American countries, these chemicals are most likely present in detectable levels in many water sources, since most of them were banned not so long ago and others are still in use]. The good news is that the application/use of most POPs has been banned in most Latin American countries. E.g. DDT and some other organo-chlorine pesticides have been banned from agricultural use in Latin America for decades now (Allsopp and Erry, 2000; Paratori, 1998). Therefore, their levels will not increase over time. However, exposure to those that are already in the environment is still a potential.

2.1.1.2. Treatment processes and Storage
2.1.1.2.1. Surface water Treatment
2.1.1.2.1.1. Filtration
The methods of drinking water filtration applied in Latin American countries and the Caribbean are discussed under the section for “ground water filtration” below. Surface water is mainly utilized for municipal water supplies and the filtration methods mostly used are; slow and rapid sand, and activated carbon filtration methods. However, there are some poor rural communities that utilize surface water as well and in these communities, household water filtration methods have been utilized as discussed under ground water filtration.

Note: the filtration methods applied for drinking water obtained from various water sources (rain water, surface water and ground water sources) are the same. The type of a
filtration method to use is dependent on the affordability; applicability; acceptability of the technique; and the desired/required output, as well as a range of several other factors as discussed under the ground water section below.

The filtration methods used for household and public water supplies may be different. Some filtration techniques will apply on household levels but cannot be used for public water supplies and vice versa. Public water supplies always use filtration methods that operate on a commercial scale.

**2.1.1.2.1.2. Disinfection**

Disinfection of Surface water in Latin American countries is mainly by chlorination. This method is applied for both public water supplies and household water treatment. In public water supplies, chlorine is used in form of chlorine gas and/or sodium- or calcium hypochlorite. At household level, chlorination of water supplies is by use of chlorine tablets. However for those communities with limited access to chlorine tablets, boiling is the most emphasized treatment method coupled with prior water filtration as discussed under ground water section.

Solar water disinfection (SODIS) is also utilized for surface water disinfection among the poor rural communities in most countries in Latin America. SODIS as a method of water disinfection in Latin America has been discussed under the ground water section below. The application and procedure is the same as for ground water and water must be filtered first to reduce the turbidity before it is subjected to solar disinfection. Poor application of SODIS has been one of the reasons for the failure of this method to control diarrheal diseases and consequently its less popularity and acceptability in some developing countries in Africa (e.g. Uganda).

**2.1.1.2.2. Storage**

The storage of surface water in Latin American countries is mainly by use of dams. However, there are significant variations in the numbers and capacity of dams for different countries and regions. These variations are somehow determined by the relative availability of alternative water sources and the climatic conditions of particular regions. For example, the northeastern state of Ceará in Brazil has a relatively big number of dams (about 7,227 dams) with accumulative storage capacity of up to 11.0 billion cubic meters
This is partly because the state is characterized by semi-arid to arid climate conditions and thus must store a lot of water to sustain the water supply need for most parts of the year (Young, 1998). There are also several water storage dams along the Amazon tributaries. One of the largest water storage dams in Brazil is the Tucurui dam, constructed on Tocantins River in the Northeastern region and has a storage capacity of up to 110.0 billion m$^3$ (World Commission on Dams, 2000). This basically helps to supplement water supply from other water sources (such as; ground water) since the region experiences long drought conditions.

2.1.1.3. Distribution
Surface water distribution in Latin America is very much inclined on the climate zones across the regions. The tropical climate regions have highest abundance of surface water resources as compared to other climate zones. The desert climate areas/countries basically don’t have any surface water resources except for a few oases which are not widely distributed. For more information on climate zones of Latin America and expected relative abundances of surface water resources for the different countries in the region, refer to Figure 30—Climate zones.

2.1.2. Ground water
2.1.2.1. Sources
2.1.2.1.1. Quantity and Utilization
Ground water aquifers in Central America and indeed the whole of S. America, are one of the most productive and best quality in the world and currently provides 80–90% of the water supply for domestic, agricultural (irrigation) and industrial purposes in the region (Bethune et al. 2007; Bethune and Ryan, 2010). S. America has about 16 ground water basins holding/containing significant amounts of fresh ground water as shown in Figure 23. The Amazon Sedimentary Basin covers an area of approximately 1.3 million square kilometers (km$^2$) and contains an estimated 32,500 cubic kilometers (km$^3$) [or 32.5 trillion m$^3$] of stored fresh ground water in its aquifers. Ground water is generally obtained from drilled wells [150 millimeters diameter, more than 100 meters deep and yields of 60 to more than 400 cubic meters per hour (m$^3$/h)] and its utilization for domestic, industrial and agricultural water supplies has been increasing, despite the high abundance of Surface water resources in the area (Aldo da C. Rebouças, 1999).
observed high dependence on utilization of ground water resources for water supplies is reflected on the water quality, limited pollution, easy accessibility, reliability for most part of the year and the relative deterioration of water quality from Surface water sources (Bethune and Ryan, 2010; Aldo da C. Rebouças, 1999).

The Paraná Sedimentary Basin is another important ground water containing area in South America. This basin underlies the most developed regions of Brazil—1 million km² and extends into eastern Paraguay—100,000 km², northwestern Uruguay—100,000 km² and the northeastern Argentina—400,000 km² (Aldo da C. Rebouças, 1999) with a very important aquifer system (Guarani). The Guarani Aquifer System which is a trans-boundary aquifer underlying the 4 countries; Argentina, Brazil, Paraguay and Uruguay contains an approximated 40,000 km³ [or 40 trillion m³] of stored freshwater reserves (Wendland et al., 2004). The aquifer extends over 839,000 km² in Brazil and 355,000 km² in the eastern part of the Chaco-Paraná Basin: Paraguay 71,700 km², Argentina 225,500 km² and Uruguay 58,500 km² (Aldo da C. Rebouças, 1999). This aquifer serves as the main source of ground water in the four countries above. Other aquifer systems also exist besides Guarani. Utilization of the ground water has significantly increased over decades, due to rapidly increasing urbanization and agricultural production across S. America (Wendland et al., 2004). It’s estimated that 77% of ground water is used for domestic purposes, and the remainder for industrial and agricultural production (GEF, 2002). In Brazil’s São Paulo State alone, about 60.5% of urban centers (over 5.5 million people) were served by ground water in the early 2000s (Wendland et al., 2004). It is most likely that this number increased over time to probably over 6 million people to-date with the current world population growth.

2.1.2.1.2. Quality Issues

Ground water quality in Latin America is generally good for domestic and industrial supply though it is unevenly distributed in quantity (Aldo da C. Rebouças, 1999). Most of the observed ground water contamination typically results from anthropogenic activities. Just like other countries worldwide with rapid industrialization and agricultural production, there has been evident contamination of ground water sources with agricultural pesticides, nitrates and a range of industrial organic chemicals. Several
analyses have shown inorganic contamination (high phosphate– \( \text{PO}_4^{3-} \) and nitrate– \( \text{NO}_3^- \) levels) and pesticide traces in ground water and have been linked to extensive agricultural activities mainly swine (pig) farming, maize and soy production (Wendland et al., 2004).

Arsenic has also been documented as one of the major contaminants in ground water in South America with some of the world’s most severe cases of arsenic-contamination ground water being detected in aquifers in Asia and in South America mainly Argentina and Mexico (Pauline L. Smedley, 2008). By 2005, the central region of Argentina (La Pampa) had aquifers producing ground water with arsenic-contamination of up to 5300 mg L\(^{-1}\) (Smedley et al., 2005). This could have been most likely due to anthropogenic activities such as, metal mining and application of arsenic based pesticides in agricultural production since these countries are known for commercial agricultural production of dairy/cattle products (Argentina) and coffee (Mexico).

2.1.2.2. Treatment processes and Storage
2.1.2.2.1. Ground water Treatment
2.1.2.2.1.1. Filtration

In many developing countries in Latin America, filtration techniques are introduced and sponsored by governmental agencies and NGOs, with full participation of the local communities. For example, in El Salvador, CESTA (Centro Salvadoreño de Tecnología Apropiada) builds and installs residential filters for rural communities at a low cost as indicated below; in Dominican Republic, the private sector, mainly the companies which produce the filtration systems, sponsor the technology; in Ecuador, NGOs (such as; CARE and Plan International), participate actively in the application of filtration systems to combat the use of polluted water; in Brazil, the government and the private sector actively develop and implement the filtration systems (Moreno et al., 1996; Edward J. Martin, 1988).

The cost of construction, installation, operation and maintenance of filtration systems in Latin America, is relatively low. Homemade residential filters in El Salvador cost $23 to construct and an annual maintenance cost of $6; commercially available tub filters (as described below under residential filters) in Dominican Republic cost $26 – $45; quarry filters used in Mexico cost $50, with little or no maintenance cost; the unit cost of slow
and rapid sand filters in Ecuador ranges from $0.13/m^3 – $0.20/m^3; slow sand filters were constructed in Ecuador at a cost of $132.30 with an annual maintenance cost of 25% of the construction cost (Moreno et al., 1996). These rates could have increased over time but the bottom line is that; they are still affordable.

Water filtration processes may remove a substantial percentage of the unwanted materials including microbes and sometimes chemicals. This usually depends on the pore size and type of the filter material used. The filter material may be any porous and chemically stable material. Sand and gravel are most often used materials in filtration systems because they are: cheap in terms of cost, chemically inert/non-reactive, durable, and readily available.

Several types of filtration systems that include; residential filters, slow and rapid sand filters, and dual media filters have been used to purify water (from both surface and ground water sources) for domestic use in many countries throughout Latin America and the Caribbean (Moreno et al., 1996). The type of water filtration system to use depends on: the availability of the filtering materials; the applicability/ease of use; the quality of raw water; flow rate; and the desired degree of water purification which is determined by the intended use of the filtered water. Some filtration systems have been tested in several countries and have shown to be effective (e.g. the vertical flow pre-filters with gravel media tried in Guatemala and the up-flow solids contact filters successfully used in Brazil). These filtration systems are effective and can possibly be applied in many developing countries worldwide since they are cheap in terms of cost and application.

**Residential Filters:** are a common form of filtration that are either homemade or commercially available. The homemade filters consist of a sand- or gravel-filled pipe or tub, while the commercial filtration systems contain materials other than sand or gravel and have a stainless steel frame, with appropriate connections/fittings to simplify the application. The filter media of homemade residential filters must be routinely changed for effective functionality. Residential filters are common in developing countries with poor quality of domestic water supplies. El Salvador, Dominican Republic, Mexico and indeed most Latin American countries promote the use of these types of filters mainly in the rural areas. The tub filter is the basic form of residential filter, used in most rural
areas with no public water supply. It consists of two joined tubs, made of either clay or plastic. The upper tub contains the filter material (e.g. sand, gravel, etc.) for filtering the water and the lower tub holds the filtered water and is fitted with a faucet/outlet for easy access of water. In El Salvador, the tub filters are homemade with a 1m long concrete pipe having a diameter of 0.5 meters (m) and fitted with a perforated pipe, which is placed at the bottom of the filter in a 10 centimeters (cm) layer of gravel and connected to a pipe with a 0.75 inch internal diameter from which the filtered water is collected. The gravel is overlain by 60cm layer of sand. The filter materials (gravel and sand) must be cleaned and sun dried before use. In Mexico, these filters are made of porous volcanic rock assembled in a wooden frame and protected by a screen. In the Dominican Republic, the filters are commercially available and are made of stainless steel, with layers of filtration materials (sand, gravel, anthracite, and activated carbon). They are usually installed at discharge point of the water storage tanks.

**Slow Sand Filters;** are mostly used for public water supplies and consist of a watertight box filled with a filtering material. The size of sand used in slow sand filters is about 0.2 millimeters (mm) but may range from 0.15–0.35 mm. In a mature bed, a layer of algae, plankton, and bacteria (schmutzdecke) forms on the surface of the sand. Inlets and outlets should be provided with controllers to keep the raw water level and the filtration rate constant. The successful performance of a slow sand filter depends mainly on the retention of inorganic suspended matter by the straining action of the sand. Filtration rate normally used in most developing countries in Latin America ranges from 2.5– 6.0 cubic meters per square meter per day (m$^3$ m$^{-2}$ day$^{-1}$). High rates may be used if the raw water to be filtered is of good quality. The filtration system needs to be designed in a flexible manner with several separate units for easy maintenance without filtration process. The number of units depends on the size of the population served and ranges from 2 units for about 2000 to 6 units for about 200,000 people. Slow sand filters have been applied in rural communities of La Pinera El Salvador and other Latin American countries. In Ecuador, slow sand filters are extensively used for both surface and ground water filtration.
During filtration using the slow sand filters, impurities are deposited on the surface layer of the sand bed which increases the head loss. At a set head loss limit (usually not allowed to exceed 1–1.5 m), the filter is withdrawn from service and cleaned. The filter can be cleaned by either scraping off 1–2 centimeters (cm) of the topmost surface layer of sand and replacing it with clean sand and the period between successive cleanings is usually 20–60 days. The filter needs to be replaced at least biannually and the bacteriological layer reactivated in the new filter which takes about 2 months.

**Rapid Sand Filters;** consist of an open watertight basin containing a layer of sand 60–80 cm thick, supported on a layer of gravel. Also mostly used for public water supplies but are more difficult to operate than slow sand filters. They differ from slow sand filters by the size of the filtration media used. Sand size ranges from 0.35–1.0 mm. This size can effectively filter water with turbidity of 5–10 Nephelometric Turbidity Units (NTUs) at a rate of up to 4.88 cubic meters per square meter per hour (m³ m⁻² hr⁻¹). Filtration rate for a rapid filter may go up to 100–300 m³ m⁻² day⁻¹ or about 50 times the rate of a slow sand filter. The number of filters used for a specific plant ranges from 3 filters for a plant capacity of 0.05 cubic meters per second (m³/s) to 10 filters for a plant capacity of 1.5 m³/s. The sand is re-graded each time the filter is backwashed, with the finest sand at the top of the bed. A clear well is usually located beneath the filters to provide consistent output quantity. The minimum number of filter units in a system is usually limited to 2 and the surface area of a unit is usually more than 150 square meters (m²) with the ratio of length: width of 1.25–1.35. Rapid sand filters are extensively used in areas with high turbidity water and limited land or space. Conventional rapid sand filtration is widely used in Latin America and other developing countries worldwide. Rapid sand filters have also been applied in rural communities of most Latin American countries (e.g. La Pinera, El Salvador, etc.). Pre-filtration using vertical reactors with gravel beds in water treatment plants have also been applied in the municipalities of Cabañas, Zacapa, and Guatemala.

Rapid sand filtration plants require frequent backwashing at a rate of about 0.6 cubic meters per minute (m³ min⁻¹) for several minutes every 24–72 hours of operation, so as to maintain satisfactory operating heads in the system. The frequency of backwashing is
determined by the concentration of suspended solids in the raw water. The initial filtered water after backwashing is channeled to waste for several minutes and thus wasting about 10–15% of the total output. However, rapid sand filters require smaller land area, produce higher outputs and perform better than slow sand filters in treating raw water with higher concentrations of suspended solids than. And can thus be used where the quality of raw water is very poor.

**Dual- or Multi-Media Filters:** Dual-media filtration uses two layers; a top layer made of anthracite and a bottom layer of sand, to remove the residual chemical-biological layer after alum, iron, or lime precipitation in drinking water treatment plants. This type of filtration system is also used in wastewater treatment plants to remove the residual biological layer contained in settled and secondary-treated wastewater effluents. The filter unit consists of an open watertight basin; filter media; support structures; distribution and collection devices for raw water, filtered water, and backwash water flows; extra cleaning devices; and controls for sequencing water flows, levels, and backwashing.

Dual-media filters are cleaned by hydraulic backwashing with clean/filtered water. Thorough cleaning of the filter bed is advisable for single medium filters, and is mandatory for dual-media filters. The use of surface wash devices before and during the backwash cycle in dual-media beds is needed to remove accumulated layer stored throughout the bed depth. Backwashing is needed every 24–72 hours of operation and usually takes 3–15 minutes to complete. After the washing process, the filtered water should flow to waste until the turbidity drops to a tolerable value.

**Up-flow Solids Contact Filter:** this type of filter performs; liquid-solid separation, filtration, and sludge removal in a single unit process. Thus the flocculators and settling tanks are not needed when using this filter system (filtration in such systems is improved by use of flocculent aids and the processes of coagulation and flocculation are done in a gravel layer underneath sand bed). The Up-flow Solids Contact Filters are designed for filtration rates of $120 - 150 \text{ m}^3\text{m}^{-2}\text{day}^{-1}$ and their use is limited to low turbidity (up to 50 Jackson’s turbidity units –JTU) raw water and with a maximum of 150 mg L$^{-1}$ suspended
solids. These filtration systems have been extensively used in South America, mainly in Brazil.

2.1.2.2.1.2. Disinfection
There is a range of water disinfection methods applied for water supplies at both household and municipal water supply levels. At the household level, disinfection methods such as boiling drinking water, chlorination, and use of solar water disinfection (SODIS) have been applied to decontaminate drinking water in many countries in Latin America. Most of the household water treatments have been applied in poor rural areas and are mostly applied by women and children with limited participation from men. The utilization of solar energy for water disinfection in most Latin American countries is feasible due to sufficient solar intensity in the region (Félix et al., 2009). Large-scale household treatment of water in rural areas in most countries in Latin America started over a decade ago with the purpose of combating the waterborne diseases. The use of SODIS was initiated in the rural Bolivia in early 2001 and has since then been a great possibility for thousands of people living in poor conditions and have no other means of obtaining clean drinking water from the available water sources in most rural areas in Latin America (Xiomara and Ana, 2001). Some pilot studies were done among the poor communities in Northeast Brazil and found SODIS to be effective for removal of most pathogenic microbes in water (Félix et al., 2009) and has thus been applied to disinfect water supplies from both ground water and surface water sources in most poor communities in Latin American countries who have limited accessibility to clean water supplies.

Chlorination as a method of water disinfection is also widely applied in Latin America for disinfection of water supplies for both household and public water supplies. Chlorination has been used extensively for all types of water (surface water, ground water and rain water).

2.1.2.2.2. Storage
Ground water storage in Latin America is somewhat similar to rain water storage. The facilities used are similar only that a ground water storage tank is connected to a water pump that pumps water from an underground aquifer; whereas a rain water storage tanks
is connected to a water collection surface by a gutter. Just like rain water, ground water can also be stored in cisterns and tanks as discussed under rain water section below.

2.1.2.3. Distribution

There are several ground water basins distributed across the whole of South America. The Central America and the Northern region have the highest amount of ground water as compared to the Southern countries. This is mainly because the northern part of South America is mainly tropical and the central is a mixture of tropical and temperate climates while the south is majorly arid and semi-arid. The amount of ground water per region is very much dependent on the recharge rates which are also reflected on the climate conditions. As a matter of fact, there is a close connection between amounts of rainfall received with the levels of ground water recharge in a given catchment area (Hughes et al., 2012). Ground water utilization around the central and northern regions of South America is extensive. This could be linked to the availability of more ground water resources in these regions as shown in the Figure 23 below (right side map).

![Figure 23](image_url)

**Figure 23**—On the Left is the Sketch Map of South America showing the distribution of the Guarani Aquifer System among the four countries of; Argentina, Brazil, Paraguay and Uruguay (Wendland et al., 2004); on the Right, is the Distribution of Zones with Higher Utilization of Ground water in South America (Aldo da C. Rebouças, 1999).
2.1.3. Rain water

2.1.3.1. Sources

2.1.3.1.1. Quantity and Utilization

For most Latin American countries and the Caribbean, the total annual rainfall received ranges from less than 500 to more than 1,500 mm (Torres et al., 1996). Most of the rainfall is received for a few months of the year, with little or no rainfall received for the remaining months. In some regions such as the Southwest and Northeast countries of South America, the annual mean rainfall received varies between 1000 mm and 1800 mm (Wendland et al., 2004).

Rain water harvesting from roofs and its utilization for domestic and agricultural purposes, has been practiced for more than 300 years in developing countries (Daniel et al., 2009; Torres et al., 1996), and has recently become essential due to substantial pollution of the available surface water sources and decreasing levels of ground water in some parts of the world. In the Caribbean and Central American countries (Honduras, Paraguay, Uruguay, Brazil, Costa Rica, Guatemala, El Salvador, Argentina, etc.), the rural communities and poor urban areas that lack access to public water supply systems, rain water harvesting has been used as a major source of domestic water supply (Daniel et al., 2009; Torres et al., 1996; Reyes et al., 1996; Schiller and Latham, 1995). For decades of years, rooftop catchments and cistern storage have been the source of domestic water supply on many small islands in the Caribbean and among Latin American countries (Torres et al., 1996; Hadwen P, 1987; Haebler and Waller, 1987; Edwards and Keller, 1984) as well as many other developing countries worldwide (Reller R, 1982). It was estimated that in the early 1990s that over half a million people in the Caribbean islands somehow depended on rain water for domestic water supply (Torres et al., 1996). This estimate could have increased overtime due to: the current world population increase; deteriorating surface water quality due to pollution from industrial and agricultural wastes; and depletion of ground water resources as evidenced in many countries worldwide. Over large geographic areas in some countries in Central and South America (such as; Honduras, Brazil, Paraguay, etc.), the use of rain water harvesting is an important source of water supply for domestic purposes, especially in rural areas (Reller R, 1982; Junker M, 1995; Keller S, 1995).
Rain water harvesting is used extensively in Latin America and the Caribbean, mainly for domestic water supply and, in some cases, for agriculture and livestock supplies on a small scale (Santos W, 1992). In Brazil and Argentina, rain water harvesting is used extensively in semi-arid regions due to limited surface water and ground water resources in these areas; in Honduras, Costa Rica, Guatemala, and El Salvador, rain water harvesting using rooftop catchments is used extensively in rural areas as a major source of clean/potable domestic water supply (Reyes et al., 1996; Schiller and Latham, 1995; Reller R, 1982) since the rural areas don’t have public water supply systems.

2.1.3.1.2. Quality Issues
Rain water usually comes with good quality but may get contaminated from the collection surfaces and during storage in tanks and cisterns and even during handling. Rain water collection surfaces also collect windblown dirt, animal droppings, decomposing leaves, etc. all of which can potentially contaminate the rain water and thus deteriorate its quality. The water that is collected from the first rains following long dry spells usually contains high load of bacterial pathogens and organics (Daniel et al., 2009) and will need to treated first to remove the organics and pathogenic microbes before it can be used for domestic purposes.
The materials of the collection surfaces and storage tanks have also been implicated in the contamination of the rain water. For some countries where rain water roofs made of asbestos sheets are used, the asbestos can easily leach into the water and end up causing health issues (e.g. asbestosis, cancers, etc.) for people who are using such water for a long time. The storage tanks are also another issue as the materials of storage tank will also leach into the water after a long storage time. Generally under conditions of limited air pollution, use of well-maintained rain water collection surfaces; and where storage tanks/cisterns made of unreactive materials are used and maintained in good sanitary conditions, rain water quality will be of good quality and will require minimal treatment.

2.1.3.2. Treatment processes and Storage
2.1.3.2.1. Rain water Treatment
2.1.3.2.1.1. Filtration
The filtration methods applied for drinking water obtained from rain water are the same as for ground water discussed in the ground water section above. The type of a filtration method adopted for use/application in a given community is dependent on the affordability; applicability; and acceptability of the technique as well as a range of several other factors as discussed under the ground water section.

2.1.3.2.1.2. Disinfection
Rain water usually has good quality but may get contaminated from the collection surfaces and during storage in tanks and cisterns. The folks using cisterns are always advised to chlorinate their water before drinking or any other domestic application. For those who can’t chlorinate the water, they are advised to at least boil the water before drinking.

Just like many other developing countries worldwide, boiling of drinking water is the most common method of water disinfection used in most rural areas in the Caribbean and Latin America. Boiling is one of the simplest methods of drinking water disinfection. The water is boiled up to full rolling boil point at 100 degrees Celsius (100°C or 212°F) for at least one minute and later allowed to cool down under clean conditions before it is used. This helps to eliminate most pathogenic microbes, mostly viruses and bacteria that cause waterborne diseases. In order for boiling to be most effective, the water must be boiled/
heated for at least 20 minutes (Margaret, and Payero, 1996). Boiling can effectively be used to disinfect water from all available sources (rain water, surface water and ground water sources).

Chlorination of water in cisterns/or storage tanks is the most used chemical disinfection method for disinfecting rain water (and any other water) intended for most domestic applications. In some countries in Latin America, chlorination systems have been established for community rain water catchment systems, e.g. the Water Authority in Montserrat Island in the Caribbean where a non-conventional chlorination device that uses chlorine tablets to chlorinate rain water supplies was constructed (Torres et al., 1996). However, in most places especially in the poor and remote rural areas, rain water is used without any chemical treatment due to limited accessibility to chlorine tablets. In such places, boiling is mostly used. In some other places the quality of rain water may be assured through the installation of commercially available in-line charcoal filters or other water treatment devices, especially for those folks using cisterns for storage.

2.1.3.2.2. Storage
In regions with low precipitation, it is necessary to store large amounts of rain water during the wet season to meet demands for domestic and agricultural water supply in droughts. In Latin America and the Caribbean, the storage of harvested rain water is by use of underground concrete cisterns or the rain water storage tanks which form an indispensable component of a functional rain water harvesting/catchment system. In these countries, the rain water storage tanks and/or concrete cisterns are made of a variety of materials and in varying sizes according to the households’ or community water requirements. The storage facilities used include; large capacity underground concrete cisterns (100–150 m³), large polyethylene tanks (1.3–2.3 m³), and steel drums (0.2 m³) for smaller households (Torres et al., 1996). In some countries in the Caribbean and Latin America (e.g. Virgin Islands, Barbados, Turks & Caicos Islands, Venezuela, etc.), the existing government regulations under the building code, make it mandatory for all typical single-level residential building establishments to have rain water storage cistern/tank large enough to store at least 0.4 m³ water per each square meter (m²) of roof area; and a number of government-built, public rainfall catchment systems have been
established in some poor rural communities, e.g. the Turks and Caicos Islands in the Caribbean. Cistern storage of rain water provides a significant domestic water supply source in Venezuela’s islands off the Northern coast (Torres et al., 1996).

![Figure 26](image)

**Figure 26**—Schematic of a Cistern-left and a Storage Tank Reservoir-Right (Santos W, 1992)

It is believed that, the rain water storage cisterns and tanks will most likely continue to be used as a principal source of water for many people in the Caribbean islands and rural areas of several countries in Latin America even after the governments’ mandatory requirements have been waived. This is mainly due to extensive rain water harvesting practice in the regions as rain water is considered safe, sufficient, and inexpensive.

Galvanized sheet metal tanks and Polypropylene plastic tanks are also presently being used in most Latin American countries for storage of household drinking water collected from rain water harvesting as well as ground water and surface water. However, these tanks are mostly used for rain water and ground water storage and rarely for surface water storage.

![Figure 27](image)

**Figure 27**—On the left is Low-Profile Polypropylene Tanks and on the Right is a Galvanized Sheet Metal Tank usually fitted with food-grade plastic liner (Daniel et al., 2009)
Another method frequently used for storage of harvested rain water, is storage in situ using areas with low topography. This practice has been used in the arid and semi-arid regions of northeastern Brazil, Argentina, and Paraguay, primarily for irrigation purposes (Anjos et al., 1996). In Paraguay, the low topography areas used for rain water storage are known as tajamares. The tajamares are served by distribution canals that deliver water from the storage area to the areas of application. Tajamares are usually connected to storage tanks and water can be pump to the storage tank usually by a windmill driven pump. Water from tajamares is normally used for agricultural purposes and can only be used for domestic consumption after thorough filtration and disinfection. In Chaco Paraguay Tajamares have also been used to artificially recharge ground water aquifers and have produced an estimated 6,800 m$^3$/yr for aquifer recharge (Anjos et al., 1996).

**Figure 28**—On the left is Low Topography Rainfall Harvesting Area–Tajamare (Anjos et al., 1996; UNEP, 2012) [http://oas.org/dsd/publications/unit/oea59e/ch11.htm](http://oas.org/dsd/publications/unit/oea59e/ch11.htm) & on the Right is an Artificial Recharge used in Paraguayan Chaco and in many other Latin American Countries (Daniel et al., 2009)

Furrows are also used to store harvested rain water in situ. They are built prior to or after planting to store water for future use by the plants. Flattened trenches between the rows of crops are used to store water as shown in Figure 29. Mud dams/ barriers at every 2–3 meters along the row are used to retain water and to avoid excessive surface runoff and erosion. Raised beds and uncultivated areas may also be used to trap the water in the furrows. Furrows have been widely used in Northeastern Brazil, Chaco region of Paraguay, and in Argentina (Anjos et al., 1996). Rain water stored in furrows can be used to supplement the water supply for agricultural purposes and sometimes domestic use.
2.1.3.3. Distribution
The regional distribution of rainfall for the different countries in Latin America differs significantly. Latin America is characterized by a mixture of climate zones. It has extremely dry desert climate, where very little or no rainfall is received for most part of the year; it also has the tropical climate areas (mainly central and northern counties) where rainfall is abundant throughout the year. The southern part of South America is mainly characterized by dry and temperate climates and these receive very little rainfall.
3.0. Chapter Three

3.1. Comparisons of Water supply systems in Uganda to those used in other Countries in the U.S., Latin America and the Caribbean

a) Uganda and U.S. compared

3.1.1. Surface water

3.1.1.1. Sources

3.1.1.1.1. Quantity and Utilization

U.S. has a rich supply of surface water from rivers, streams, creeks, lakes, and etc. providing approximately 80% of the total day-to-day water requirements (mainly for thermoelectric power, public water supply, irrigation, aquaculture, mining, and industrial purposes). Seventy-seven percent (77%) of this water is fresh water and the remaining 23% saline water. Most of the freshwater is utilized for thermoelectric power, irrigation and public water supplies to metropolitan areas. Countryside homes mainly utilize ground water from privately owned wells.

Comparatively, Uganda has less surface water resources than U.S. Surface water is mainly obtained from rivers, streams, and lakes and is utilized majorly for piped public water supplies in the metropolitan areas and industrial purposes. In rural and poor urban slums, surface water is utilized by approximately 20% of the population mainly for domestic water supply. Agricultural (mainly irrigation) application of surface water is not yet developed in Uganda.

3.1.1.1.2. Quality Issues

In the U.S., most common contaminants in surface water are metals (such as; Pd, Cd, As, etc.), organic chemicals (pesticides and herbicides), nitrates from a range of industrial and agricultural applications and pathogenic microbes. Nitrate contamination of surface water has been noted in areas with a lot of livestock production and where nitrates are applied as soil fertilizers to boost production of food and cash crops such as; corn, cotton, and vegetables. Drinking water quality in the U.S. for all public water supplies is regulated under state and federal laws and codes, which set Maximum Contaminant Levels for a number of pollutants, determine various minimum operational requirements and require utilities to publish consumer confidence reports. There are requirements specific to facilities using surface water sources and/or ground water under direct
influence of surface water surface water as per the Surface Water Treatment Rule (SWTR). The major enforcing body is the U.S. EPA, thus states and water districts strive to ensure compliance with the U.S. EPA’s drinking water quality guidelines. The quality of water from the privately owned water sources is not regulated under federal laws and is thus not included in the U.S. EPA’s drinking water guidelines.

In Uganda, the major water quality issues are connected to microbial contamination mainly resulting from direct influence of sewage and other poor sanitation and hygiene practices. Chemical contamination with heavy metals and organic chemical applied in agriculture is still on a very low scale. Water quality is regulated under the National Drinking Water Quality Guidelines adopted from the WHO drinking water guidelines. However, these guidelines are mostly observed for the piped water supplies which are limited to metropolitan areas. In rural and poor urban slum areas, surface water quality monitoring is not a common practice.

3.1.1.2. Treatment processes and Storage

3.1.1.2.1. Surface water Treatment

3.1.1.2.1.1. Filtration

In the U.S., the Surface Water Treatment Rule under the 1986 Safe Drinking Water Act (SDWA) Amendments requires the water supply systems using surface water and ground water under the direct influence of surface water, to filter their water supplies. Filtration of water at public water supply plants is mostly by slow sand filtration. Other systems that treat surface water with high organic loads use activated carbon filters to achieve maximum removal of organics from the water. In some states, surface water filtration for public water supplies is strictly by activated carbon filtration.

In Uganda, surface water filtration is done at NWSC treatment plant. The method of filtration used is rapid gravity filtration using fine lake sand filtration bed. In the rural and poor urban slum communities with no connection to NWSC public water supplies, water filtration is often not practiced. Potable water is often provided without any filtration.

3.1.1.2.1.2. Disinfection

In the U.S., surface water is distributed through municipal water supplies and undergoes disinfection at municipal water treatment plants. Most water treatment plants in the U.S.
use chlorination to disinfect water. Some utilities use ozone, chlorine dioxide, chloramines, or a combination of chemicals added at different points during treatment. The choice of the disinfection method to use usually depends on the quality of raw water and the associated costs of using a particular disinfectant.

In Uganda, surface water is utilized in both urban and rural areas. The urban areas basically use water supplied by NWSC which undergoes chlorination using sodium hypochlorite and chlorine gas before it is distributed. In the rural and poor urban areas, surface water disinfection is by boiling, SODIS and home based chlorination as discussed under ground water section below.

3.1.1.2.2. Storage
In the U.S. water storage tanks are utilized for both the water treatment plants and at household level to ensure a continuous supply of drinking water.

Storage of surface water in Uganda is discussed under “sub-section 3.1.2.1.2.2.” below

3.1.1.3. Distribution
In Uganda, surface water is mainly limited to Central, Western, some parts of Eastern regions and areas around the Lake Victoria as indicated in Figure 1. The Northern and Northeastern regions have less surface water resources with most of the rivers in the regions being seasonal.

In the U.S. surface water from the rivers occurs in almost every state but states with arid and semi-arid climate conditions have less amounts of surface water. Besides, U.S. also has an abundance of saline water from the surrounding oceans which can be desalinated and used for agriculture and domestic water supplies and any other applications. Uganda is landlocked and thus has no access to sea water.
3.1.2.  Ground water

3.1.2.1.  Sources

3.1.2.1.1.  Quantity and Utilization

The U.S. has a rich ground water resource. Almost all states in the country have a lot of ground water. The U.S. uses roughly 315.325 million cubic meters (m$^3$) of ground water per day (20% of the total water used daily). Domestic self-supplied water especially in country side of US is almost exclusively ground water. Ground water is also utilized for public water supplies in urban areas though most of the fresh ground water withdrawals (about 68%) are used for irrigation purposes and public water supplies take only 19%. Ground water utilization for domestic purposes and other applications (such as; agriculture and industrial uses) in the U.S. has increased over years due to an increase in population growth rates, industrialization and the consequential pollution of freshwater from Surface water sources.

In Uganda total renewable ground water resources are estimated to be about 29.0 million m$^3$/year with about 20,000 deep boreholes; 3000 shallow wells; and 12,000 protected springs mainly in rural and poor urban slums. Ground water is the most important potable water source for the people in rural communities and provides more than 80% of the water supplies. Though ground water development in Uganda has been ongoing for a long time, its utilization for public water supplies in urban areas and for agricultural as well as industrial applications is not yet practiced in the country. Ground water in Uganda is exclusively used by the rural and poor urban slum dwellers for provision of domestic water supplies.

3.1.2.1.2.  Quality Issues

In the U.S. ground water quality is mainly affected metals (e.g. As, Fe, Mn, etc.), pesticides and nitrates contamination resulting from anthropogenic activities such as mining and agriculture. Some of the metal pollution (such as pollution by Fe, Mn, and As) occurs naturally from the soil and water holding rock formations that naturally contain these metals. High nitrate (as nitrogen) levels have also been measured in shallow ground water in the US particularly in areas with well-drained soils and have also been linked to intensive agricultural production of food and cash crops such as; corn, cotton, and vegetables. The U.S. EPA regulates the occurrence of Fe, Mn, As, Pb and NO$_3^-$ in
municipal water supplies by setting maximum contamination limits (MCLs) which all water districts in the U.S. must comply with. The regulation of ground water quality for the self-supplied households is not covered by U.S. EPA drinking water guidelines.

In Uganda, ground water quality is mainly affected by pathogenic microbial and nitrate (NO$_3^-$) contamination resulting from poor sanitation and hygiene practices such as poorly sited pit latrines, faulty sewage systems, poor drainage and waste management systems, etc. Fecal coliforms and high NO$_3^-$ concentrations have been measured in shallow ground water sources mainly from poor urban slum areas as a result of localized pollution from the numerous poorly located pit latrines and poor drainage systems. Chemical and heavy metals contamination of ground water in Uganda is still very low since mining and industrial development isn’t yet widespread in the country and the application of pesticides and fertilizers for agricultural production is still very low among rural communities where ground water is utilized. Fluoride is the major inorganic contaminant in Uganda’s ground water and is limited to only those areas/regions with volcanic rocks and soils.

3.1.2.2. Treatment processes and Storage
3.1.2.2.1. Ground water Treatment
3.1.2.2.1.1. Filtration

In the U.S., water filtration is practiced for both municipal water supplies as well as at household level. It’s estimated that about 20% of U.S. households have some type of water filtration or purification system installed. Slow sand filtration, rapid sand filtration, microfiltration, granular activated carbon filters have been used in the U.S. and the method of filtration used is basically dependent on the target contaminant in the water. Filtration has been used to remove organic contaminants and metals such as As, Fe, and Mn from water supplies in the U.S.

In Uganda, filtration is not a common practice among the communities where ground water is utilized. Ground water utilization is mainly by the rural and poor urban slums where water is used without any filtration.
3.1.2.2.1.2. Disinfection
In the U.S., chlorination is the major disinfection method applied for most water supply systems. UV and ozonation disinfection methods are also used especially in water treatment plants for Small Communities. The U.S. EPA is particularly concerned about disinfection of ground water systems that are susceptible to fecal contamination and thus requires all public water supply systems using surface water and ground water under direct influence of surface water to disinfect the water and regularly monitor the bacteriological quality. However, these standards don’t apply to privately owned wells as mentioned earlier.

In Uganda, since ground water is utilized mainly in the rural and poor urban slum areas, the most common water disinfection methods used are boiling and chlorination. Chlorination is used at both household level and at water sources in form of hypochlorite solutions and chlorine tablets. Another method of water disinfection used is solar water disinfection (SODIS) though not widely used technique.

3.1.2.2.2. Storage
In the U.S. there are established water storage systems (water- tanks). Municipal water supplies and individual households have water storage tank(s) to ensure continuity in water supply.

In Uganda, water storage for communities utilizing ground water is not well developed since it is mostly used by rural and poor urban communities who lack properly organized storage systems like water-tanks.

3.1.2.3. Distribution
In the U.S., ground water exists in all the states though some states have more ground water resource than others. The states with dry (arid and semi-arid) climate have relatively less ground water than other states. Ground water distribution has also been characterized using withdrawal rates and the used to which withdrawn ground water is put. States (California, Texas, Nebraska, Arkansas, and Idaho) with the highest withdrawal rates of ground water were basically using it for irrigation which takes a lot of water. This implies an abundance of ground water resources in these states.
In Uganda, ground water distribution varies significantly for different regions. Some parts of the country, such as the Northeastern region have limited ground water resources. Besides, the states that have relatively more ground water, haven’t exploited the resource well.

b) Uganda, Latin America and Caribbean compared

3.1.3. Surface water
3.1.3.1. Sources

3.1.3.1.1. Quantity and Utilization
There are large quantities of freshwater from surface water sources (mainly lakes, rivers, and streams) in Uganda, Latin America and the Caribbean. These basically supplement the domestic water supplies from other sources of potable water (ground water and rain water sources). There are some similarities in the surface water sources used by rural populations in Uganda and among the developing countries in Latin America and the Caribbean. However, utilization of surface water sources contrasts significantly for these countries. In Latin America and Caribbean, surface water is utilized for domestic water supply as well as agricultural production; whereas in Uganda, surface water is mainly utilized for piped domestic water supply in the metropolitan areas. In Uganda’s rural and poor urban slums, surface water is utilized on a small scale and is used by only about 20% of the population mainly for domestic water supply and a small portion of it, for livestock production.

3.1.3.1.2. Quality Issues
Pollution of surface water sources in Uganda and other countries in Latin America and the Caribbean is a big hindrance to potable water accessibility from surface water sources. Anthropogenic activities (e.g. agriculture, industrialization, sewage disposal, etc.) are major contributors of pollution to surface water sources in these countries. Most of the available fresh surface water sources in Uganda, Latin America and the Caribbean rate poorly in terms of bacteriological and chemical quality assessments, with the major polluting factor being poor sewage disposal systems. In Uganda, the use of latrines, poorly designed septic tanks and faulty/ dilapidated sewage systems significantly pollute surface and shallow ground water sources. There are specific regulations that require siting of pit latrines and septic tanks not less than 30 meters uphill of a water source.
(spring, shallow well, etc.). However, this is usually not followed in poor urban slum areas due to disorganized/poorly planned settlement patterns (see figure 5). Likewise in Latin America, most households in the metropolitan areas use simple septic tanks for sewage disposal and thus significantly polluting the environment mainly surface water and shallow ground water sources. In addition, there are still large knowledge gaps with respect to water and sanitation activities and the control of waterborne diseases among the local populations in these countries.

One major difference in surface water quality from Uganda and that from Latin America and the Caribbean lies on the quantities and composition of the chemical contaminants in these waters. In general, Uganda’s surface water sources chemical contaminants concentrations are less that those found in Latin American and Caribbean waters. This is mainly due to the extensive chemical applications mainly for agricultural activities observed in Latin American countries as compared to Uganda. Another explanation could be that there are a limited number of studies on the chemical contaminants in Uganda’s surface water. There are less persistent organic pollutants (POPs) mainly pesticides in Uganda’s surface waters since their application for agricultural production is not as developed as it is in Latin American countries. However, most surface water sources in Uganda, mainly lakes are undergoing eutrophication due to high nutrient inflows (mainly phosphates and nitrates) with the main source being sewage and other organic materials.

3.1.3.2. Treatment processes and Storage
3.1.3.2.1. Surface water Treatment
3.1.3.2.1.1. Filtration
The practice of water filtration is much more practiced in Latin America and Caribbean than it is practiced in Uganda. In Uganda, water filtration is only done at the water treatment plants as one of the treatment processes for the NWSC piped water supplies. Water filtration in the rural and poor urban slums in Uganda is not a common practice. Water is just obtained from the source and used without any prior filtration. This applies to all types of available water (surface water, rain water and ground water supplies). However, in Latin America and the Caribbean, water filtration is a common practice for both municipal water supplies and at household level. Several filtration methods are used to filter potable water at home (residential filters) and public water supply plants (slow
and rapid sand Filters, dual- or multi-media filters, and up-flow solids contact filter) in the metropolitan areas as well as among the rural communities with limited or no access to public water systems.

### 3.1.3.2.1.2. **Disinfection**

For the public water supplies, chlorination is a common water disinfection method applied in Uganda and other countries in Latin America and the Caribbean. The wide application of chlorination as a method of disinfecting public water supplies is mainly due to; the low costs involved, high efficiency of chlorine at killing a wide range of pathogens and the biocide residual that it provides.

The water disinfection methods used for rural populations with no access to public water supplies are quite similar for these countries. For example in Uganda, Latin America and the Caribbean boiling is the most emphasized method of water disinfection at home. Other methods such as use of chlorine tablets and SODIS have been applied in these areas. However, SODIS as a method of potable water disinfection has been more successful and extensively applied in rural areas in Latin America and Caribbean than in Uganda. The major reason for limited popularity of SODIS in Uganda is mainly due to limited public acceptance as people think that it is not effective for drinking water disinfection. The actual the problem is wrong application of the method that has made it look like it is not helpful at all.

### 3.1.3.2.2. **Storage**

In Uganda, organized surface water storage systems (mainly storage tanks) exist only for the water treatment plants in an effort to maintain a continuous water supply. Each municipal water treatment plant has storage tanks that can store more than one day of production from the plant, so as to keep the water supply system running just in case of breakdowns. At the house hold level, water tanks of up to more than 5000 liters (5.0 m³) are used mainly for those households with piped water connections in urban areas, but these comprise a very small proportion of the urban population. In the rural and poor urban communities with no NWSC piped water connections, there are no organized systems for storage of water. The water is mainly stored in the small containers of up to 5 – 20 liters (0.005 – 0.02 m³) where it is fetched from the source.
In Latin American and Caribbean countries, the storage of surface water is mainly by use of dams though there are significant variations in the numbers and capacity of dams for different countries and regions as determined by the relative availability of alternative water sources and the climatic conditions of different regions. The countries/regions with semi-arid to arid climate conditions tend to have more dams for storage enough water during wet seasons so as to sustain water supply needs for most parts of the year.

3.1.3.3. Distribution
Regional variations in surface water availability do exist in Uganda, Latin America and the Caribbean countries. These are mainly determined by the prevailing climatic conditions. The only difference between Uganda, Latin America and Caribbean lies in how the water shortages mainly in semi-arid and arid climate areas are being managed in Latina America and Caribbean. Unlike Uganda where not much has been done in ensuring constant accessibility to water in semi-arid regions of Northeast and some parts of North, in Latin America, dams have been constructed mainly in dry areas so to trap and store huge amounts of water that can be used in dry seasons of the year. This has ensured relatively better water accessibility to potable water in such regions as compared to Ugandan situation.

3.1.4. Ground water
3.1.4.1. Sources
3.1.4.1.1. Quantity and Utilization
Though Uganda is said to have a relative large amount of ground water, Latin America and the Caribbean have significantly richer sources of ground water, providing up to 90% of the total water supplies for domestic, agricultural (irrigation) and industrial purposes for both rural and metropolitan areas. Ground water development in Uganda has been ongoing since the 1930s through construction of boreholes, shallow wells, springs and rehabilitation of old and faulty ground water sources, providing domestic water supplies to about 80% of the population in the rural and poor urban slum areas especially in the Eastern and Northern regions of the country. Ground water utilization for agricultural production (irrigation) in Uganda has not been implemented in Uganda due to inaccessibility and poor extraction methods. In fact the communities utilizing ground water in Uganda don’t get sufficient amounts to cover all their domestic needs. Ground
water utilization for domestic water supply has not even introduced in the urban centers in Uganda.

On the other hand, utilization of the ground water in Latin America and the Caribbean has significantly increased over decades, due to rapidly increasing urbanization and agricultural production across the regions. It’s estimated that 77% of ground water is utilized for domestic water supply, and the remainder for industrial and agricultural production. South America has well developed mechanical extraction methods for ground water using efficient wind driven pumps coupled with enough storage facilities that have enabled utilization of ground water for industrial and commercial agricultural production.

The observed high dependence on ground water resources for water supplies is a result of the water quality, limited pollution, easy accessibility, reliability for most part of the year and the relatively little deterioration of water quality compared to surface water sources.

3.1.4.1.2. Quality Issues
Generally, if properly maintained the quality of ground water especially from the deep wells, is good enough even without any disinfection since the water undergoes natural soil filtration before recharging in the aquifers underground. Whereas the ground water-quality in Uganda is mainly affected by bacterial contamination resulting from poor sanitation facilities and hygiene practices, in Latin American countries and the Caribbean contamination of ground water mainly originates from industrial and agricultural sources.

In Uganda, fecal coliforms and high nitrate concentrations have been measured in shallow ground water sources mainly from poor urban slum areas as a result of localized pollution from the numerous poorly located pit latrines and poor drainage systems. Chemical contamination of ground water in Uganda is still very low since industrial development isn’t yet widespread in the country and the application of pesticides and fertilizers for agricultural production is still very low among rural communities where ground water is utilized. Fluoride seems to be the major inorganic contaminant in Uganda’s ground water and is linked to volcanic rocks and soils.

In Latin America and the Caribbean, ground water pollution usually results from anthropogenic activities (industrialization and agriculture) that contaminate ground water
sources with pesticides, nitrates and a range of industrial organic chemicals. High levels of inorganic pollutants (PO$_4^{3-}$ and NO$_3^-$) and pesticides in ground water have been linked to extensive agricultural activities mainly swine farming, maize and soy production. Arsenic is also one of the major contaminants in ground water in Latin America and has been linked to metal mining and application of arsenic based pesticides in agricultural production.

Despite the existing ground water-quality problems, ground water supply systems remain the most important and feasible source of safe drinking water in Uganda, Latin America and the Caribbean since ground water doesn’t require a lot of treatment processes like surface water. The investment and operational costs of ground water systems are way less than those of surface water systems and thus can be afforded in rural and poor urban communities.

3.1.4.2. Treatment processes and Storage
   3.1.4.2.1. Ground water Treatment
      3.1.4.2.1.1. Filtration
In Uganda ground water is utilized by the people living in rural and poor urban slums. In these communities, potable water filtration is not practiced. In Latin America and the Caribbean, ground water filtration methods used are the same as for surface water and rain water. Filtration has been discussed under surface water section above. In comparison, Latin America and the Caribbean are still performing better since water filtration is also practiced at household level using the residential filters, something that is still lacking in Uganda.

5.1.4.2.1.2. Disinfection
In Uganda, ground water is used only in the rural and poor urban slum areas. The most common water disinfection method used is boiling. Chlorination is also used at household level and at water points in form of hypochlorite solutions and chlorine tablets under the trade name of water guard. This method of drinking water disinfection has been frequently used during waterborne disease epidemics and is mostly provided by the NGOs operating in the rural communities where they provide drinking water accessibility services. Another method of water disinfection used is solar water disinfection (SODIS) though not widely used.
In Latin America and Caribbean, ground water is utilized for both municipal water supplies in metropolitan areas as well as rural communities. Water disinfection used especially for the municipal water supplies is chlorination. This is also used at household level informal of chlorine tablets. SODIS has also been used extensively in the rural communities in South America where access to chlorinated public water supplies is limited.

3.1.4.2.2. Storage
In Uganda, storage of ground water is not well established since it is mostly used by rural and poor urban communities who lack organized storage systems (water tanks). This has been one of the major causes of school going children frequenting water sources to fetch water for their families and hence losing so much of their school time.

In the Latin American and Caribbean countries, storage of ground water is well developed. There are special storage tanks/reservoirs especially for the public water supply systems. This makes water accessibility from ground water sources possible for most time of the year. However, the storage of ground water at household level in poor communities without connection to public water supplies is not as organized as most households don’t have storage tanks. But there are communal storage tanks mainly provided by NGOs and governments where people can easily access their potable water supplies.

3.1.4.3. Distribution
There are significant variations in regional distribution of ground water in Uganda, Latin America and the Caribbean. Ground water distribution in Uganda and Latin America is much reflected on the climatic conditions. Areas/regions with tropical climate and thus receive significantly large amount of rainfall have an abundance of ground water than dry regions with little or no rainfall. Logically, tropical areas have higher rates of ground water recharge resulting from rain water infiltrations than the semi-arid and arid areas with very little recharge.
3.1.5. Rain water
3.1.5.1. Sources
3.1.5.1.1. Quantity and Utilization
Rain water is an effective alternative source of potable water supply in developing countries that receive adequate amounts of rainfall annually. Uganda receives annual rainfall ranging from 500 mm in the Northeastern region to 2500 mm in Southwestern regions and the areas in and around Lake Victoria basin. Rain water harvesting and utilization in Uganda is only among rural populations and is still on a relatively small scale. Successful projects using rain water harvesting have implemented seen in Southwestern region Central region, and in a few Districts in Eastern Uganda mainly rural primary schools, churches and a few households.

On the other hand, in Latin America and the Caribbean countries, annual rainfall ranges from <500 mm in semi-arid and arid regions to more than 1,800 mm in tropics. Most of the rainfall is received for a few months of the year, with little or no rainfall received for the remaining months. So the situation is not a lot different from Uganda’s. Rain water harvesting is extensively used as a major source of domestic water supply mainly among rural areas with limited access to public water supply systems. However, rain water harvesting is also practiced in metropolitan regions with access to public water supplies.

The major difference is that; unlike Uganda, rain water is much more extensively utilized in both rural and metropolitan areas among countries in Latin America and Caribbean for both domestic water supply as well as agricultural production. Uganda still lags behind in this sector.

3.1.5.1.2. Quality Issues
Rain water quality in Uganda, Latin America and the Caribbean basically faces similar quality issues arising mainly from the materials, as well as sanitary conditions and maintenance of the storage tanks and collection surfaces. The quality of rain water is generally good where sanitary conditions of the storage tanks and water collection surfaces are maintained in a good state.
3.1.5.2. Treatment processes and Storage

3.1.5.2.1. Rain water Treatment

3.1.5.2.1.1. Filtration

In Uganda, rain water is mainly utilized by people in the rural areas where water filtration is not a common practice. In Latin America and the Caribbean, the filtration methods used for rain water are the same as for ground water and surface water and have been discussed under surface water section above. Thus in comparison, Latin America and Caribbean are still much better than Uganda when it comes to water filtration for both commercial and household water systems.

3.1.5.2.1.2. Disinfection

There are methods of water disinfection that are common to Uganda, Latin America and Caribbean countries. These basically include boiling, chlorination (using chlorine tablets) and SODIS. These methods are used to disinfect water from all the available water sources. However, SODIS is more extensively applied in Latin America and Caribbean than it is in Uganda.

3.1.5.2.2. Storage

For any functional rain water collection system, there must a water storage tank or cistern. In Uganda, the collected rain water is mostly stored in tanks, and jars which are either made of plastic material, concrete and cement or corrugated iron coated with steel material. The capacity of these storage tanks ranges from 400 liters (0.4 m³) for jars used at household level to over 4000 liters (4.0 m³) used for collection systems. The most commonly used by rural households in Uganda, are jars and ferro-cement tanks. Large capacity plastic and iron material tanks are mostly used for institutions like rural primary schools.

In Latin America and the Caribbean, rain water storage systems are quite similar to Uganda’s only that they have more developed and advanced storage systems and methods such as use of underground storage tanks, cisterns, tajamares, furrows and low lying areas to store much bigger volumes of rain water. These methods of rain water storage haven’t been used in Uganda.
3.1.5.3. Distribution
There are significant variations in regional distribution of rain water in Uganda, Latin America and the Caribbean. Rain water availability and distribution is determined by climatic conditions. Areas with tropical climate receive significantly large amounts of rainfall for most parts of the year than dry (arid and semi-arid) regions.
4.0. Chapter Four

Recommendations on some of the potential opportunities for improving drinking water supplies in Uganda and an analysis of the cost-benefit and obstacles present to implement the recommended activities

4.1. Recommendations on some of the potential opportunities for improving drinking water supplies in Uganda

4.1.1. Surface water

Considering the quality of water from lakes in Uganda as described earlier in “Chapter One” and in an additional statement below by one of the directors of NEMA in 2010 about Lake Victoria, it’s clear that not enough has been done to protect surface water sources in Uganda. This also evidently demonstrates that, the water treatment process used by NWSC to treat potable water from lakes is too basic for such kind of water and thus doesn’t provide ideal measures to attain the standard requirements for potable water.

—Gerald Sawula, Deputy Executive Director of National Environmental Management Authority – NEMA (2010). Lake Victoria’s Murchison Bay, the northerly inlet on which Kampala City sits, is becoming a “dead” zone. “It is a real crisis; the water has turned completely green with algae blooms swamping the whole place. The water has become so thick from effluent that is being discharged directly into the lake because the wetlands that used to filter it have all been destroyed by developers. As more algal blooms, phosphates, nitrates, heavy metals and fecal matter all pile into the lake, it’s going to be harder to clean the water. It’s very obvious that in future the NWSC won’t be able to treat water from L. Victoria to a level safe enough for domestic consumption.”

Thus there is an urgent need for an overhaul of the entire regulatory process so as to strengthen measures for protecting surface water sources as well as improving bacteriological and chemical quality of drinking water supplied by NWSC for public water supplies. The available treatment processes of screening, coagulation, flocculation, sedimentation and rapid gravity filtration, can only treat the water to a certain extent. In that regard, we recommend that more effective measures/activities such as those listed below be considered where possible;

– The first concern is to increase/improve protection of the watershed areas. This can be possibly done through implementation and proper/strict observation of the government legislations, policies and laws on potable water quality supply and
protection of natural water resources. This would in turn help to control the observed high levels of pollutants reaching the available surface water sources from industrial, agricultural, and sewage effluents as well surface runoffs.

- There is an urgent need for intensive and extensive health education on proper sanitation and hygiene practices especially to the local populations inhabiting the islands and lakes shore as well as the fishing populations, since these folks tremendously pollute the lakes by naively disposing of excreta directly into lake waters. This coupled with strict laws and heavy punishments on violators could help protect and increase good quality water supplies from the available surface water sources mainly lakes and rivers.

- Considering the quality of the raw water, the use of fine lake sand for rapid gravity filtration of water most likely doesn’t remove as much organics as required of potable water supplies. Thus the use of activated carbon filters or better still slow sand filtration (considering the high cost of using activated carbon filters) should be considered as one of the options especially for the removal of organic pollutants that will have by–passed the coagulation, flocculation and sedimentation steps, before any chemical disinfection is done. This will not only improve the chemical quality of water but also the bacteriological quality.

- The introduction of home–based filtration by use of residential filters which are locally made through the use of locally available materials could come in handy for the folks in rural and poor urban communities who use highly turbid and contaminated surface water from ponds, rivers and other available sources. These filters can also be commercially available, but the locally made are cheaper and would thus be affordable to Ugandan rural & poor urban slums communities and thus sustainable. The use of residential filters to clean domestic water supplies is practiced in rural areas for most developing countries in Latin America with poor quality of domestic water supplies and no access to public water supplies.

- Looking at disinfection method used and the quality of raw water as describe earlier, using Cl₂ exclusively to disinfect the water, may potentially pose problems concerning chemical quality of water due to probable formation of DBPs linked to high organic loads (TOC) in raw water. Besides, this has an effect on effectiveness of
Cl₂ disinfection and will increase Cl₂ demand (Darby et al., 2005). The use of chlorine dioxide \([\text{ClO}_2]\) in combination with chlorine gas for disinfection would help a lot to improve the bacteriological quality of treated water as well as controlling the formation carcinogenic chlorination by-products (DBPs) in drinking water. That way, the people using the water, are not only protected from the acute health outcomes usually associated with poor bacteriological quality, but also chronic health outcomes as a result of exposures to DBPs in chlorinated water. \(\text{ClO}_2\) has a chemical reactivity that clearly differs from other oxidants (such as; \(\text{Cl}_2\)). It can effectively oxidize many water pollutants (e.g. Sulphide, Reduced Sulphur compounds, Nitrogen compounds, Cyanides, Phenols, Aldehydes, Amines, THMs precursors, Pesticides, Algae slime, and Metals). \(\text{Cl}_2\) reacts with THM precursors (humic and fulvic acids) by oxidation and electrophilic substitution to yield both volatile and non-volatile chlorinated organic substances (THMs). \(\text{ClO}_2\) however, reacts with humic and fulvic acids mainly by oxidation to make them non-reactive or unavailable for THMs formation. This implies that treatment with \(\text{ClO}_2\) prior to addition of \(\text{Cl}_2\) has an inhibitory effect on THMs formation. \(\text{ClO}_2\)’s behavior as an oxidizing agent is quite unique, in that; instead of combining with the aromatic rings, it breaks these rings apart and consequently, causing a sharp fall in the levels of generated chlorinated organics (DBPs) as the use of \(\text{ClO}_2\) increases.

- The use of infiltration galleries near the lake should be given a thought so as to allow the heavily polluted lake water undergo natural soil filtration to remove most of the organic matter and pathogenic microbial contaminants before it’s pumped into the treatment plant for further treatment. This will tremendously reduce the burden on the water treatment plants and thus improve the quality of final treated potable water in terms of bacteriological and chemical quality.

- The surface water quality for the people living in the rural areas is generally poor. These folks obtain water from the sources such as; ponds, rivers, seeps, lakes, streams, etc. in untreated form. Thus the water quality issues are very much different from the people in urban centers who use piped water. These people basically need more sensitization on how to treat the water before using it for human consumption. More than often the water has very poor bacteriological quality since it obtained from
unprotected sources that are very prone contamination by human and animal feces carried by runoffs mainly. Protection of these water sources through excavation of surface diversion channels to divert surface runoffs before reaching the source water and also fencing for those using water ponds can help to reduce the contamination pathways. Also where possible, more development of ground water so as to limit dependence on surface water should be looked since ground water is of better quality than surface water and is also less prone to contamination.

4.1.2. Ground water

Uganda still greatly lags behind in ground water resource utilization for all applications including potable water. Unlike in the U.S., Latin America and the Caribbean where ground water is utilized extensively in rural and metropolitan communities and for a wide variety of applications, ground water in Uganda is only utilized by the folks living in rural and poor urban slum areas mainly for potable water supply. Besides there are still huge knowledge gaps about ground water resource development, protection and utilization among the communities that use ground water as well government and other stakeholders involved in ground water resource development. We therefore recommend that more emphasis be put on the following activities so as to realize more benefits from ground water resources in Uganda;

– Extending ground water resource utilization for both the rural and urban areas. Currently, the people in urban centers entirely use piped water supplied by NWSC and ground water is not utilized at all. Considering the quality of surface water as observed in the previous section, utilizing ground water wouldn’t only supplement the surface water resource but would also be financially beneficial to the government since ground water is relatively cleaner than surface water and will thus cost less money to treat. The boreholes in Uganda are mostly drilled with funding from NGOs and occasionally the government. Moreover, households using ground water from nearby boreholes don’t pay for the water except for the small well–pump maintenance fee of about Shs. 1000 (about 50 cents in U.S.) per month, which is basically very little money. So in a sense people will save a lot of money that would otherwise have been spent on paying piped water bills.
For the rural communities with no access to piped water, more boreholes need to be drilled so as to increase accessibility to portable water. In some regions such as Eastern, Northern and Northeastern regions where ground water is almost the only source of water available for most parts of the year, accessibility to potable water is still limited due to an inadequate number of water points. The argument has always been lack of enough information on how many wells to drill in a particular area without necessarily causing competitive abstraction and drying up of aquifers. For example, the Uganda National Water Development Report of 2005 highlights the challenge of competitive abstraction as one of the practical concerns for the protection and development of ground water resources in Uganda. That there is a big knowledge gap concerning the capacities and spans of ground water aquifers available in the country, and as such, it is hard to determine how many pumps to drill in a given area without having to face the challenge of competitive abstraction and drying up of aquifers. However, this doesn’t sound a valid concern as far as ground water accessibility issues in rural Uganda are concerned because; the abstraction rate of ground water from a particular aquifer is not determined by the number of wells connected to it, but rather on the volume of water being pumped out which corresponds to the number of people using the particular water source. Up to now, there are still lots of concerns of water accessibility in rural Uganda areas that basically stem from poor planning aggravated by existing knowledge gaps. This has only left the poor and unprivileged rural and urban slums populations suffering relentlessly.

There is a need for fast, zealous, and extensive health education to the local folks especially those using shallow ground water sources in poor slum areas, on proper hygienic and sanitary handling and maintenance of water as well as the sources. The major concern about the quality of ground water in Uganda (as discussed in Chapter one) is mainly pathogenic microbiological and nitrate contamination that results mainly from point sources such as; pit latrines built in catchment areas for the ground water sources, decomposing solid-waste heaps, poor sewage disposal coupled with poor drainage systems where liquid waste ends up flooding around, and many other shortcomings. People generally need to be educated on how to keep their ground
water sources safe and also how to maintain hygienic and sanitary conditions at home. In addition to this, there is a need for strengthening the government legislations/laws on community sanitation and hygiene practices. It is always the role of the households to ensure proper sanitation practice, as stated under the Public Health Act, but this can always be achieved where there is a strict observation and implementation of the laws.

4.1.3. Rain water

Though rain water harvesting in Uganda provides a relatively safe source of potable water supply to communities especially in rural areas, its utilization is still on a very small scale. Rain water harvesting and utilization is currently being practiced mostly in rural areas among the regions receiving reasonably adequate amount of rainfall. Though there are significant regional variations in the amount of rainfall received annually, every region at least has a certain period of the year when they receive significant amounts of rainfall. Harvesting of rain water has been implemented in many institutions (mainly rural primary schools and churches) and these projects have recorded tremendous contribution towards the control of diarrheal diseases among the school going children, but the practice at household level is still meager. We thus recommend that more importance be put on the following activities so as to effectively utilize rain water resources in Uganda;

- Extensive campaign for rain water harvesting countrywide especially in areas where is no connection to public water supplies
- Construction of communal rain water harvesting/collection structures/systems with large water storage tanks/cisterns in rural and poor urban slum areas to supply households who can’t afford privately owned rain water collection and storage tanks.
- Incorporation of the rain water collection systems in the state building laws/rules for all the new structures put up
- Collection and storage of surface runoff in low land areas. This can later be used for other applications other than domestic water supply such as irrigation and for livestock
– Sanitation and hygiene promotion/campaign on maintenance of storage tanks and cisterns clean as well as hygienic handling of water at home. In addition easy to clean water tanks should be encouraged as opposed to the traditionally used which are very hard to clean since their interior can barely be accessed.
– Encourage all households to have some water storage facilities installed so as to supplement the communal rain water systems

4.2. An analysis of cost-benefit and obstacles present to implement the recommended activities

4.2.1. Cost-benefit Analysis
Every year about 1000–1500 boreholes are drilled in Uganda with a success rate approximated at 83% (Ron Sloots, 2010). This means that about 17% of the boreholes drilled in a year dry up after a few months of operation and considering the cost of a single borehole (Shs.15.0 million); a lot of money has been lost in the process. In order to attain an efficient, cost effective and sustainable development of ground water sector, more qualified professionals are needed to carry out pilot surveys so as to ascertain ground water availability before any drilling is done.

There is no fixed cost for drilling a borehole, so estimates based on the most current market rates are typically used during budgeting. This takes into consideration both the direct costs (borehole items/components, staff payments, fuel, etc.) and indirect costs (depreciation & overheads). The direct costs are easy to estimate and usually range from Shs. 5.6–8.1 million; but indirect costs are dependent on many factors e.g. equipment price, staff salaries, etc. The total cost of drilling a new borehole usually ranges from Shs. 7.5–15.2 million depending on the contractor’s charge. Table 2 shows an estimated cost of drilling borehole as adopted from a report on assessment of ground water investigations and borehole drilling capacity in Uganda by Ron Sloots, 2010 funded by the Republic of Uganda–MWE and UNICEF (US$ 1 = 2490 Ugandan Shillings).
Table 2: Estimating the cost of drilling a borehole in Uganda. The price quotations are stated in Ugandan Shillings/currency (Ron Sloots, 2010).

<table>
<thead>
<tr>
<th>Item</th>
<th>Minimum</th>
<th>Maximum</th>
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<tbody>
<tr>
<td>Direct costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casing/ borehole components, Staff payments, fuel, etc.</td>
<td>3,750,000</td>
<td>4,250,000</td>
</tr>
<tr>
<td>Borehole location</td>
<td>300,000</td>
<td>800,000</td>
</tr>
<tr>
<td>Fuel for cars</td>
<td>500,000</td>
<td>1,500,000</td>
</tr>
<tr>
<td>Commissions</td>
<td>1,000,000</td>
<td>1,500,000</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>5,550,000</strong></td>
<td><strong>8,050,000</strong></td>
</tr>
<tr>
<td>Indirect costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Profit, depreciation, commission, and %ge for otherwise drilling successful borehole, amount depends on % success rate expected</td>
<td></td>
<td>600,000</td>
</tr>
<tr>
<td>Depreciation</td>
<td></td>
<td>2,000,000</td>
</tr>
<tr>
<td>Overhead</td>
<td>1,000,000</td>
<td>2,000,000</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>1,000,000</strong></td>
<td><strong>4,600,000</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6,550,000</strong></td>
<td><strong>12,650,000</strong></td>
</tr>
<tr>
<td>Profit (min = 10%, max = 20%)</td>
<td>655,000</td>
<td>2,530,000</td>
</tr>
<tr>
<td><strong>Total Selling Rate</strong></td>
<td><strong>7,205,000</strong></td>
<td><strong>15,180,000</strong></td>
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Considering the annual expenditure budget of about Shs. 23.1 billion (NWSC, 2010) for NWSC to supply of piped water to the urban areas in Uganda, and comparing that to the cost of drilling boreholes to abstract ground water, it would be much cheaper to supply water to the populations if more attention is given to ground water resource development and utilization. The annual budget of supplying piped water to urban areas is enough to drill about 2000 boreholes. Besides, once the boreholes are drilled, the water is free (only a small well maintenance fee of about Shs. 1000 per month is paid) for the people to access the water which would tremendously cut public expenditure on potable water. This will also help to check on the quality of piped water through a reduction on the amount of water treated per day which in turn makes it possible to incorporate improved water treatment procedures such as enhanced filtration methods using activate carbon filters or slow sand filtration technique and improved chemical disinfection methods. Though Uganda cannot stop using water from the lakes for public water supplies, the use of ground water and rain water resources will help to supplement surface water which in turn will ease the burden on water treatment facilities and thus allow a chance for use of better water treatment processes.
The development of ground water coupled with rain water harvesting can surely promote water accessibility in Uganda. The issue of water accessibility is worse in rural areas and poor urban slums. In the urban areas, with to piped water connections, only about 71% of the urban population has access to good quality potable water (Mutikanga et al., 2009). This means a significant proportion of the urban proportion don’t have access to the water which makes ground water development necessary.

4.2.2. **Major Obstacles to Implementation of the Recommended Activities**

- Inadequate funds/meager government budget/financial allocations for implementation of potable water development activities;
- Huge knowledge gaps concerning sanitation and hygiene among the local folks; and water resource development on side of stakeholders;
- Weak/poor implementation and observance of government legislation/laws;
- Political influence, where the government priorities don’t have much consideration for improving water supplies;
- Corruption and embezzlement of funds allocated for water resource development.

4.3. **A summary of the priority activities that can be implemented to improve Uganda’s water supplies**

- Protection of the watershed and water–catchment areas through implementation and strict observation of the government legislations, policies and laws on potable water quality supply and protection of natural water resources. This will certainly help to control pollution resulting from industrial, agricultural effluents, etc. and clearing of wetlands around lakes.
- Construction of communal rain water harvesting and sufficient water storage facilities for rain water as well as ground water especially in areas with limited water resources, such as Northeastern, Northern, Eastern and Ankole-Masaka dry corridor regions, so as to ensure a continuous supply of domestic water using rain water stored during the rainy season.
- Extension of ground water and rain water utilization to the metropolitan areas, so as to minimize on over dependence on surface water supplied as piped water by NWSC.
This will reduce government budget on water treatment since it’s cheaper to treat ground water than surface water.

- Incorporation of the rain water harvesting systems as a requirement for all new building structures in the State building rules. This law was enacted in Venezuela and it recorded a great success as per rain water harvesting and utilization in the country. It is now believed that even after this law is lifted from the building rules, rain water harvesting will never stop because it has become a custom among the local populations and people view it as a very effective source of clean and free water for domestic use.

- Drilling more boreholes in rural and poor urban slum areas to assist in addressing potable water inaccessibility among these communities.

- Incorporating activated carbon and slow sand filtration techniques in potable water treatment processes to reduce on the issue of organic contaminants in the water. The currently used filtration method (rapid gravity filtration) can’t possibly remove most of the organics from the water.

- Introduction of home–based residential filtration of domestic water for the folks in rural and poor urban slum communities who do not have access/connection to public water supplies by NWSC and thus obtain their poor quality domestic water supplies from ponds, streams, rivers, lakes and other undeveloped water sources. Besides, home–based filtration will come in handy especially where chlorine tablets are used to disinfect water at household level, since filtration helps to reduce turbidity in water and thus enhance effectiveness of Cl\textsubscript{2} disinfection.

- Use of chlorine dioxide [ClO\textsubscript{2}] in combination with chlorine gas for disinfection of public water supplies by NWSC as this would help to improve the bacteriological quality as well as control formation carcinogenic chlorination DBPs in drinking water.

- Intensive and extensive health education on proper sanitation and hygiene practices especially to the local populations. Aspects of keeping potable water hygienic/clean at home as well as preventing contamination of water at the source should be clearly communicated to the local folks. In addition, there should constant follow-up exercises to ensure communities’ adherence to proper sanitation and hygiene.
practices at household and community levels. This is critical for sustainability of potable water supply systems.

4.4. **Expected benefits**

- The quality of potable water in Uganda would improve reducing the incidence of waterborne diseases in the country;
- Medical care costs associated with the treatment of water borne diseases will be reduced or avoided. This will in turn boost the economy;
- Workers would lose less of their work days to water borne diseases and thus increasing the overall productivity and boost in the economy;
- Increasing accessibility to water would mean less time dedicated to obtaining drinking water from the sources. This in turn will allow school going children to have more time for school and women to have enough time to involve in income generating activities since they are the ones who walk distances to fetch water for their families;
- The recommendations to use infiltration galleries and to provide greater source water protection, would help reduce the costs associated with treating raw water and ultimately saving the government some money that can be utilized for other activities aimed at boosting economic development.
References


Allsopp Michelle and Erry Bea, 2000: POPs in Latin America; a review of persistent organic pollutant levels in Latin America, University of Exeter, Exeter EX4 4PS, UK.


Bekithemba G., 2005: Short-cutting the Phosphorus cycle in Urban Ecosystems, PhD Thesis


Haruna R, F. Ejobi and E.K Kabagambe, 2005: The quality of water from protected springs in Katwe and Kisenyi parishes, Kampala city, Uganda


Oyoo Richard, 2009: Deteriorating Water Quality in the Lake Victoria Inner Murchison Bay and its impact on the drinking water supply for Kampala, Uganda. NWSC, 2009


Rev Reuben Byomuhangi, 2007: Adapting Water Management to the consequences of climate change; focusing on rain water harvesting and other technologies. Diocese of Kigezi Water and Sanitation Program- Rain water Harvesting


Ron Sloots, 2010: Assessment of Ground water Investigations and Borehole Drilling Capacity in Uganda. Government of Uganda (MWE) and UNICEF

Santos Walter W, 1992: Rain waters crops for use domestically. Comayagua, Honduras, agricultural development, water resources management training center.


World Health Organization (WHO) and UNICEF, 2006: Meeting the Millennium Development Goal (MDG) for Drinking Water and Sanitation Target; The Urban and Rural Challenge of the decade.


<table>
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<th><strong>Glossary</strong></th>
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<tr>
<td><strong>Public Water System (PWS):</strong> The Safe Drinking Water Act defines a Public Water System (PWS) as a system that provides water via piping or other constructed conveyances to the public for human consumption. All public water supplies are classified according to the number and type of persons served and thus we have; community water systems (e.g. towns and rural water districts); non-transient, non-community water systems (such as schools and factories); non-community water systems (such as rest stops and parks); and much smaller systems referred to as minor water systems. All these PWS are regulated by existing national and local governmental legislations/laws.</td>
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<td><strong>Point Water Sources:</strong> Point water sources are also referred to as Individual/residential water supplies (IWS). They include; well–points, dug–wells, springs and shore–wells (also known as infiltration galleries or cassion wells). Well–points, dug–wells, springs and shore–wells are very prone to pollution from pathogens, spills, surface runoffs, etc. and drought effects.</td>
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<tr>
<td><strong>Biological Oxygen Demand (BOD):</strong> the amount of oxygen required for microbial metabolism of organic compounds in water at certain temperature over a specific time period. The amount of oxygen required for complete oxidation of organic compounds to carbon dioxide and water through generations of microbial growth, death, decay, and anthropophagy is total–BOD. It is dependent on temperature, nutrient concentrations, and the enzymes available to indigenous microbial populations. The BOD value is usually expressed in milligrams of oxygen consumed per liter of water during 5 days incubation at 20°C and is often used as an indicator of organic pollution in water as well as determining the effectiveness of drinking water and waste–water treatment plants.</td>
</tr>
</tbody>
</table>
| **Total Organic Carbon (TOC):** the amount of carbon bound in an organic compound and is often used as a non-specific indicator of water quality. TOC is used to measure water quality during the drinking water purification process. TOC in source waters comes from decaying natural organic matter (NOM) and from synthetic sources. Humic acid, fulvic acid, amines, and urea are types of NOM. Synthetic sources include; detergents,
agricultural and industrial chemicals, and chlorinated organics. Before source water is treated for disinfection, TOC provides an important role in quantifying the amount of NOM in the water source.

— **Disinfection by-products (DBP):** DBP consist of a wide variety of chemicals that form when chlorine is added to water for disinfection purposes during the treatment process. Cl₂ reacts with naturally occurring fulvic, humic and amino acids, and other natural organic matter as well as bromide and iodide ions forming DBP: e.g. Trihalomethanes (THMs), Haloacetic acids (HAAs), Haloacetonitriles (HANs), 3-chloro-4-dichloromethyl-5-hydroxy-2(5H)-furanone (MX), halofuranones, halonitromethanes, haloamides, chlorite, iodo-acids, iodo-THMs, nitrosamines, etc. THMs and HAAs are the most often found in chlorinated drinking water.

— **Environmental Impact Assessments (EIAs):** An EIA simply put, is an assessment of the likely positive and negative effects/impacts that a proposed development may have on the environment. The International Association for Impact Assessment – IAIA defines an EIA as “the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to any key decisions on implementation are taken”. The purpose of the EIAs is to ensure that decision–makers consider the most probable consequential environmental impacts when deciding whether to proceed with a project. EIAs require decision–makers to fully account for environmental values and justify their decisions in light of detailed environmental studies and public observations on the probable environmental impacts of the developments.

— **Millennium Development Goals (MDGs):** These are eight international development goals that all 193 United Nations member states and at least 23 international organizations have agreed to achieve by the year 2015. They include: eradicating extreme poverty and hunger; achieving universal primary education; promoting gender equality and empowering women; reducing child mortality rates; improving maternal health; combating HIV/AIDS, malaria, and other diseases; ensuring environmental sustainability; and developing a global partnership for development. Looking closely at these goals, one realizes that they 100% centered on global public health promotion and in this case, portable water supply activities play a central role in achieving these goals.
Persistent organic pollutants (POPs): POPs are chemical compounds that are resistant to environmental degradation through chemical, biological, and photolytic processes. They are capable of long-range transport to regions where they have never been used or produced; bioaccumulate in human and animal tissue; biomagnify in food chains; and have the potential to adversely impact on human health and the environment globally. Several POPs are currently applied as pesticides; and others applied in industrial processes for production of a variety of products such as; solvents, PVC, and pharmaceuticals. Most POPs are anthropogenic, produced mainly in industrial processes, either intentionally or as by-products.

Schmutzdecke: This is an intricate biological layer/film that usually forms on the surfaces of slow sand filters. It consists typically of decaying organic matter; a jellylike biofilm containing bacteria, fungi, protozoa, rotifera and a range of aquatic insect larvae; and metals (such as iron, manganese, silica). It acts as a fine filter contributing to the removal of colloidal particles from raw water as well as provides bio-purification (degradation of soluble organics) which is essential for the removal of taste, odor and color from drinking water. The schmutzdecke will tend to contain more algae and larger aquatic organisms (e.g. snails, annelid worms, etc.) as it ages.

Safe Drinking Water Act (SDWA): This is the main federal law concerned with the quality of drinking water in the U.S. It empowers U.S. EPA to set standards for potable water and also to supervise all the states, and any other water suppliers in ensuring that these standards are applied and followed always. However, SDWA does not cover private wells serving less than 25 people. This Act was passed by Congress in 1974 with the major aim of protecting public health through regulation public drinking water supply. It was later amended in 1986 and 1996 to include actions required to protect sources of drinking water (such as, operator training; funding for water system expansions, and public information) as important components of ensuring supply of good quality potable water right from source up to the consumer tap.

Maximum Contaminant Level (MCL): The utmost level of a contaminant/pollutant that is acceptable/or tolerable in drinking water. For feasibility reasons, the MCLs are usually set putting into consideration the best available treatment technology and costs
involved. In other words, the MCLs must be enforceable standards given the available resources.

--- Units Used

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>µg L⁻¹</td>
<td>— Micrograms per liter</td>
</tr>
<tr>
<td>cm</td>
<td>— Centimeters</td>
</tr>
<tr>
<td>JTU</td>
<td>— Jackson’s turbidity units</td>
</tr>
<tr>
<td>km²</td>
<td>— Square kilometers</td>
</tr>
<tr>
<td>m</td>
<td>— Meters</td>
</tr>
<tr>
<td>m²</td>
<td>— Square meters</td>
</tr>
<tr>
<td>m³</td>
<td>— Cubic meters</td>
</tr>
<tr>
<td>m³/s</td>
<td>— Cubic meters per second</td>
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<tr>
<td>m³/year</td>
<td>— Cubic meters per year</td>
</tr>
<tr>
<td>m³ m⁻² day⁻¹</td>
<td>— Cubic meters per square meter per day</td>
</tr>
<tr>
<td>m³ m⁻² hr⁻¹</td>
<td>— Cubic meters per square meter per hour</td>
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<tr>
<td>m³ min⁻¹</td>
<td>— Cubic meters per minute</td>
</tr>
<tr>
<td>mg L⁻¹</td>
<td>— Milligrams per liter</td>
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<td>ml</td>
<td>— Milliliters</td>
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<tr>
<td>mm</td>
<td>— Millimeters</td>
</tr>
<tr>
<td>NTUs</td>
<td>— Nephelometric Turbidity Units</td>
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