# A CATCHMENT TO CONSUMER APPROACH TO RURAL WATER RESOURCE ASSESSMENT

## Baseline Study and Safe Drinking Supply Strategy for Orongo Village, Lake Victoria Basin, Kenya

Minor Field Study 2003/04

**KEN LEVICKI**

**Master of Science Thesis**

Royal Institute of Technology (KTH)

STOCKHOLM, SWEDEN 2005

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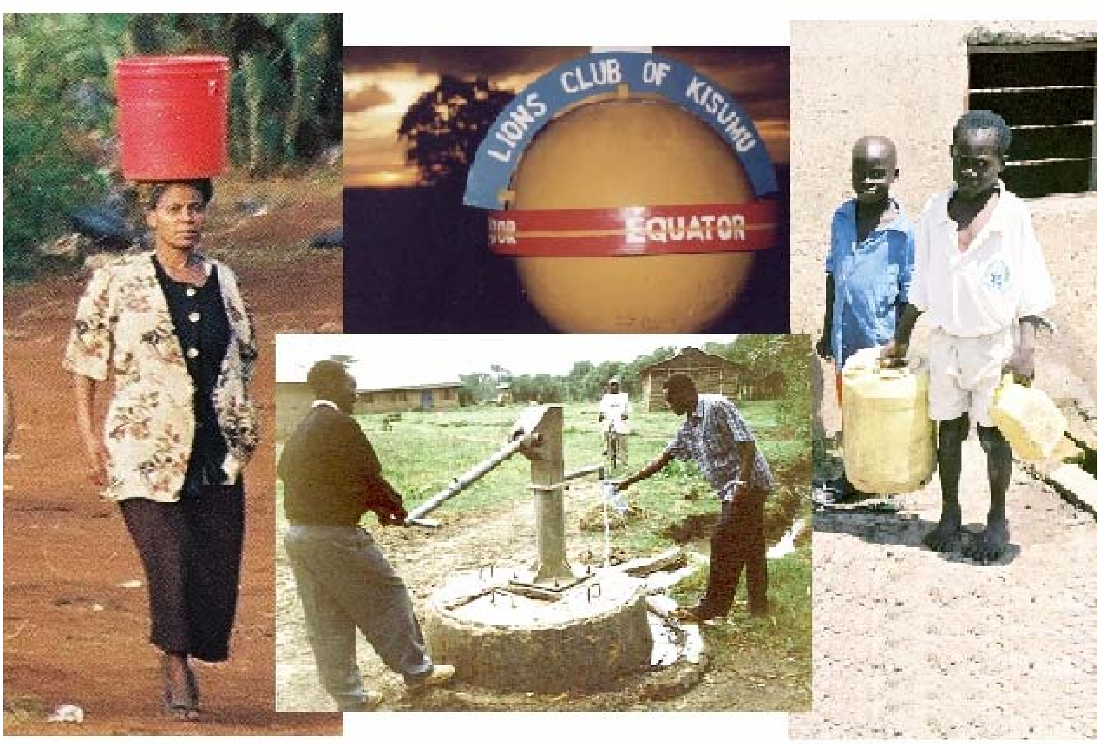

Supervisor: Lennart Nilson

STOCKHOLM 2005

ROYAL INSTITUTE
OF TECHNOLOGY

# PREFACE

This study has been carried out within the framework of the Minor Field Studies Scholarship Programme, MFS, which is funded by the Swedish International Development Cooperation Agency, Sida.

The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work, usually the student's final degree project, in countries in Africa, Asia and Latin America. The results of the work are presented in an MFS report, which is also the student's Master of Science Thesis. Minor Field Studies are primarily conducted within subject areas of importance from a development perspective and in a country where Swedish international cooperation is ongoing.

The main purpose of the MFS Programme is to enhance Swedish university students' knowledge and understanding of these countries and their problems and opportunities. MFS should provide the student with initial experience of conditions in such a country. Overall goals are to widen the Swedish human resources cadre for engagement in international development cooperation as well as to promote scientific exchange between universities, research institutes and similar authorities as well as NGOs in developing countries and in Sweden.

The International Office at the Royal Institute of Technology, KTH, Stockholm, administers the MFS Programme for the faculties of engineering and natural sciences in Sweden.

Sigrun Santesson
Programme Officer
MFS Programme

# Abstract

Orongo village is a sustenance farming community situated near Kenyan Lake Victoria. Extremes exist in rainfall patterns and climate depending on season and physical topography, so lake-shore communities face water quality deterioration from both periods of scarcity and flooding due to their low lying plain location. Poor sanitation and upstream pressures exacerbate conditions. Extreme rates of rural child mortality exceed 200 per 1000, indicating that there are serious water-related problems.

Like most of the rural Lake Victoria region, water infrastructure is very limited and poorly maintained, with most drinking sources of sub-satisfactory quality. There is widespread faecal contamination in both the shallow well water, although it appears clear, and in the highly turbid streams. Deep boreholes, though safe microbiologically, have naturally high fluoride levels at twice the WHO standard that is a cause for longer-term concern. Approximately one third of the village relies largely upon visibly polluted and untreated river water for their drinking needs, as wells collapse in the waterlogged ground.

This thesis presents an approach to water resources assessment (WRA) and development of a safe water strategy as adapted to a rural, developing community. The first half of the report assesses the current status of drinking sources available in Orongo and identifies contamination risks from upstream, at the village water points, and usage in the household. Water issues are considered in context with the health, social, economic, and political conditions of the village.

The second half of the thesis takes the conclusions drawn from the WRA and proposes a strategy to providing safe drinking water to Orongo at a household level. Lasting benefit requires a combination of water treatment, safe water storage, health education, and adequate sanitation; applying an approach from the WHO's guidance on water quality protection and control from source to consumer. Treatment methods are evaluated and compared in terms of effectiveness, cost, and operational process.

The most important aspects to address in Orongo village's strategy towards safer drinking water are:

1) repair and better protection of existing wells
2) improved hygiene practices and education to prevent cross contamination
3) expanded rooftop rainwater harvesting to utilize a better source
4) catchment protection and improved sanitation to address sources of pollution and prevent new cycles of contamination
5) economically and technologically appropriate treatment methods that can be implemented with minimal financial investment, locally available and natural materials, and simple guidance

Rainwater harvesting, hardly utilized today, has the potential to provide good quality drinking water to nearly all 3000 residents with construction of only 16 large storage tanks systems on various communal buildings. Solar disinfection and solar pasteurization is appropriate for the clear, but microbiologically contaminated shallow wells. Highly turbid surface water can be effectively treated in a two step process: bio-clarification and partial disinfection using Moringa oleifera seed powder, combined with pathogen destruction by SODIS.

An integrated "catchment to consumer" approach, with full awareness of the sources of contamination and required protection measures from both upstream, and within the household, is necessary to improve the quality and safety of water supplies for Orongo village. This approach should have relevance to other communities in the Lake Victoria region with similar natural conditions and a comparable economic, social, and political environment.

Key words: Kenya, Lake Victoria, Winam (Nyanza) catchment, water resources assessment, Hazard Analysis and Critical Control Points, water point survey, fluorosis, rainwater harvesting, household water treatment, solar disinfection (SODIS), Moringa oleifera, biological clarification and disinfection.

## ACKNOWLEDGEMENTS

I would like to take the opportunity to thank the following people and organizations that assisted in making this thesis possible.

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Dr. Phoebe Nyawalo (LAVISCA School Project) and my supervisor in Kenya Dr. Phillip Raburu, for their guidance and help in getting me started around Kisumu. Stanley Nyoni and Engineers Without Borders Sweden for introducing me to the idea of research work in Kenya.

My supervisor at KTH, Lennart Nilson, for his constructive advice and guidance.

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Ken Levicki

Stockholm, 2005

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*History teaches us that men and nations behave wisely once they have exhausted all other alternatives*. – Abba Eban

"*All people, whatever their stage of development and social and economic condition, have the right to have access to drinking water in quantities and of a quality equal to their basic needs*." - UN Conference at Mar del Plata, 1977

# 1. INTRODUCTION

Our need for water is absolute, essential for our and every other organism's survival. As a universal solvent, water effectively dissolves many minerals and organic compounds. Soil and rock composition – most substances and materials coming in contact, have a tremendous influence on its purity. Specific trace minerals are required as nutrients for living organisms, but due to anthropogenic activities, our water resources have become unfit for direct consumption at an alarming rate. Our bodies contain on average 60% water, and every day 3% is replenished with new molecules directly from the water we drink. (Suzuki, 2002) As it filters through our body, water and the contaminants it commonly carries becomes part of our cells and very composition. Even in the absence of immediate infection or noticeable health effect, the quality of water we drink should be a concern that everyone takes seriously.

Water resources assessment is defined as "the determination of the sources, dependability, extent, and quality characteristics of water resources, on which is based an evaluation of the possibilities for their utilization and control" (Falkenmark, 1980). A rational development of water resources requires as a basis a proper assessment of its current status; quantity and quality of the water available, and of the consumption and expected demand. Also relevant is an assessment of risk and factors contributing to diminished or degraded supply.

The WHO Guidelines for Drinking-water Quality (GDWQ) are adopting the concept of Water Safety Plans and HACCP (Hazard Analysis - Critical Control Points). The WHO GDWQ emphasizes the identification of key health-related quality constituents for which health-based guideline values are established. Emphasis is placed on a management system to manage and monitor water quality from source to consumer according to a Water Safety Plan (WSP), to encourage stakeholder participation and mobilization, and to stress the need for communication and education about water quality and how safe water quality can be achieved. It is recommended that HACCP be applied in the context of a Water Safety Plan that addresses source water quality, water collection, water treatment, water storage and water use. (Sobsey, 2002)
A Water Safety Plan includes:
1) risk assessment to define potential health outcomes of water supply,
2) system assessment to determine the ability of the water supply system to remove pathogens and achieve defined water quality targets,
3) process control using HACCP,
4) process/system documentation for both steady state and incident-based (e.g., failure or fault event) management.

There seems to be a need to apply this "catchment to consumer" approach to drinking water safety in a way that is appropriate for a rural developing community. This should address the most significant contamination risks and identify feasible protective measures for the upstream watershed, at the water point, during treatment, and handling within the home.

## 1.1. Maps

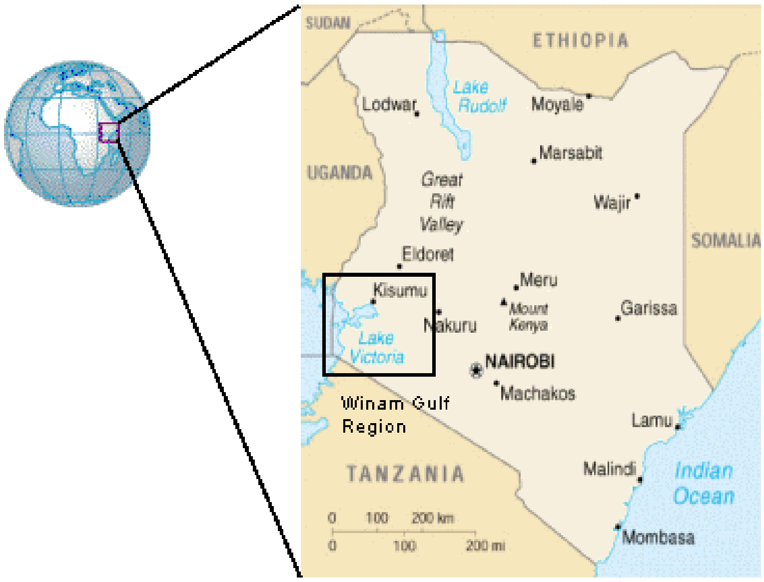

**Figure 1. Kenya within East Africa, largest cities, and the Winam (Nyanza) Gulf region in south west Kenya** (Encyclopaedia Britannica, 2001)

Kenya facts:

Area total: 582,650 sq km
land: 569,250 sq km
water: 13,400 sq km

Population: 32,021,856
approx. 80% rural
20% urban
Largest cities: Nairobi, Mombassa, Kisumu, Eldoret, Nakuru, Nyeri

Ethnic groups: Kikuyu 22%, Luhya 14%, Luo 13%, Kalenjin 12%, Kamba 11%, Kisii 6%, Meru 6%, other African 15%, non-African (Asian, European, Arab) 1%

Religion: Christian 78%, indigenous beliefs 10%, Muslim 10%, other 2% (World Factbook, 2004)

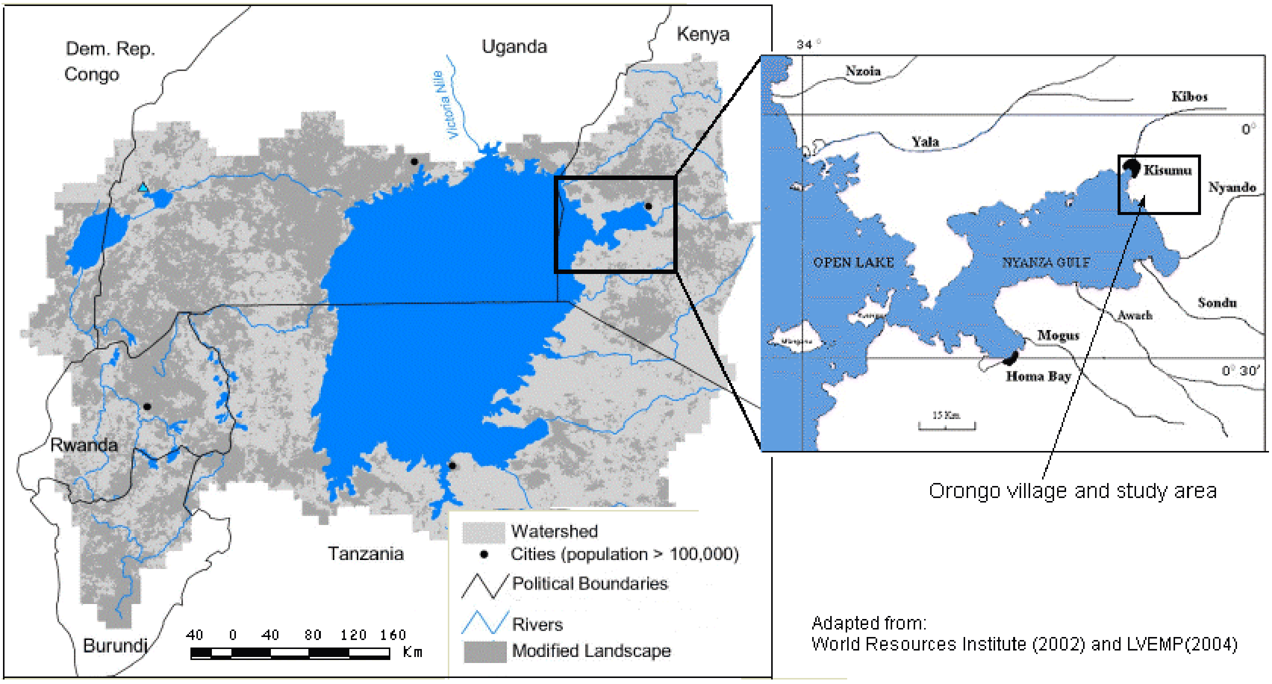

**Figure 2. Winam Gulf within Lake Victoria; Inset: Study region and main rivers.**

Winam Gulf Characteristics

Mean depth: 12 m offshore, 4 m inshore
Maximum depth: 43 m offshore, 6 m inshore
(Lake Victoria mean 40m, max 84m)

Maximum breadth: 30 km
Maximum length 70 km
Shoreline: 500 km
Area: 1400 km$^2$

Volume: 13.1 km$^3$
(Lake Victoria volume: 2,760 km$^3$)

Outflow to Lake Victoria: 0.68 km$^3$ / yr
Inflows: 3.2 km$^3$ / yr
Water retention time: 19.3 years
Maximum fluctuations: 3 m (+/- 1.5m)

Major rivers into Winam Gulf: Nyando, Sondu-Miriu, Kibos, Nyamasaria, Kisian, Awach, and Mogus

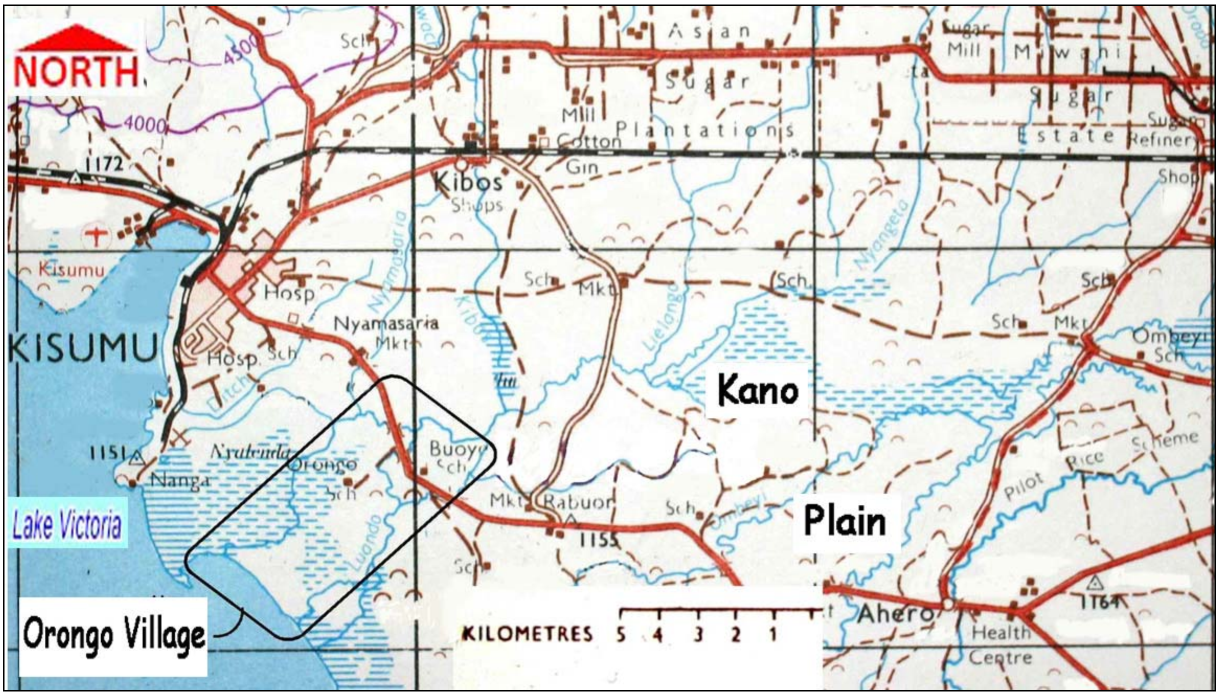

**Figure 3. Orongo Village location and study area** (Survey of Kenya, 1983)

| Orongo Village Study Area Characteristics: | | Location: |
|---|---|---|
| Population: about 3000 people | * Significant marsh area between village | on Kano Plain, 6 km south east |
| Total area: about 10 $km^2$ | and lake, therefore most homes 2-3 km | from Kisumu off Nairobi Road |
| Effective density *: 600 / $km^2$ | north east of the Winam Gulf | Luanda stream on eastern border |

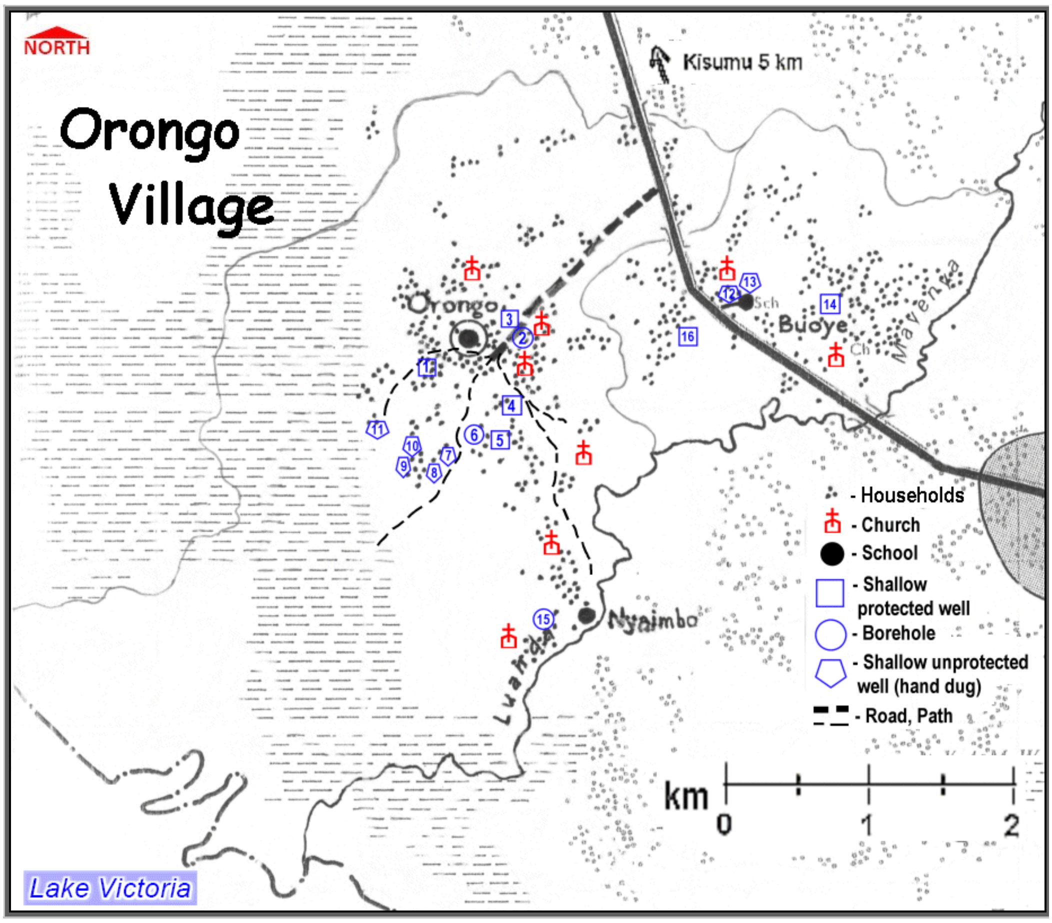

**Figure 4. Orongo Village main features and water points**

## 1.2. Background and Problem

Freshwater in Africa is unevenly distributed spatially and temporally. According to the water stress index, Kenya is one of nine water-scarce countries in Africa. It is also one of the poorest countries in the world with a high fertility rate and growth rate. Although the rate of population growth is predicted to decrease over the next decade, there still will be tremendous demand on all types of resources and basic services.

According to the United Nations, Kenya rates medium in human development and in terms of performance towards the Millennium Development Goals: “far behind” in halving the proportion of undernourished people, “slipping back” in reducing by two-thirds the under-five and infant mortality rate, and “lagging” in terms of halving the proportion without access to improved water sources (WWAP, 2003). Infant and under-five mortality rates have increased by 30 percent between 1989 and 2003 (CBS, 2003).

The green hills and the flat lowlands near Lake Victoria are agriculturally very fertile and receiving appreciable annual rainfall. However the region has the most densely settled rural areas and some of the poorest living conditions in Kenya, which worsened during the previous government that largely deprived them of national assistance and investment. One indicator, child mortality, has children in Nyanza province most at risk; nearly 4 times more likely to die by age 5 than in Central Province (CBS, 2003), and nearly 50 times as compared to Sweden. Water related disease has been a common occurrence, as cholera, typhoid, and bilharzias are endemic in the Lake Victoria region.

A worsening trend in clean water access was experienced in the 90’s compared to the 80’s; reflective of an overall lower quality of life in Kenya the past 10-15 years. (CBS, 2002)
Nearly all of the drinking sources for Orongo village can be classified as non-potable according to the WHO. The majority of residents are consuming substandard water and approximately one quarter relies upon extremely polluted surface water.

Orongo is marginalized even within the region. Most rely only on sustenance agriculture for means of living, with limited income generating potential, which minimises or eliminates cash available for drinking water improvements. Environmental conditions contribute to the economic and health problems. Long dry-periods pressure water supplies and limits agriculture to one cropping per year, while low lying elevation results in seasonal flooding. Poor quality water due to flooding, lack of infrastructure, geology, and poor sanitation, spreads water-related disease and exacerbates living conditions.

## 1.3. Purpose and Objectives

The objectives of this study are to:

- Assess baseline conditions and the current status of water resources for Orongo village, as a pre-study for potential improvements.
- Apply aspects of the WHO Water Safety Plan approach that focuses on drinking water management, contamination hazard identification, and resource protection, from “catchment to consumer”. This addresses risks for contamination from within the upstream catchment area, village drinking water points, and handling in the home.
- Give recommendations concerning water supply and treatment systems that can improve availability of safer drinking water throughout the year, and be acceptable from an economic, technical, and social basis. The recommended water supply and treatment

methods should be culturally acceptable, effective, and based on locally available, low cost materials, and simple to construct, maintain, and teach to others.
- Promote a greater awareness of how to protect sources from contamination, and more hygienic water handling practices.
- Identify further information required for better understanding the Orongo area, and which may aid in the future implementation of water improvements.

In terms of treatment methods and alternatives, the best strategy may not necessarily be to produce the highest quality water in all aspects, but rather to identify the most significant problems and determine what is required to provide at least modest improvements. The simplest, cheapest methods should be applied in order to spread the resources and benefit to as wide range of people as possible. The aim should be "some for all, rather than all for some'. (Davis, 1995)

## 1.4. Scope and Limitations

This thesis presents an approach to drinking water assessment, protection, and improvement for a developing rural community, with a field case study focusing on Orongo village beside Lake Victoria in western Kenya. The general approach is intended to be applicable across the region, but specific observations will be more relevant in rural communities with similar natural conditions and comparable socio-economic conditions.

The target audience is residents of rural villages, NGOs, government departments, and development organisations involved in planning, funding, and implementing community level water improvements in the Lake Victoria region. This study deals mostly with water quality, but health, social, and economic information is included to establish local context conditions. Since data was scarce for the Orongo area, much information was gathered from neighbouring area studies and regional statistics.

The emphasis is on factors affecting drinking water quality; as for Orongo it is more of a pressing concern than volume available. Own water samples were taken for analysis, but finances did not allow for a statistically valid set of samples that represented all village water points. The field visit and hence sampling was during a relatively dry period, although quality is expected to be significantly worse during the wet season.

This report does not involve detailed mapping of hydro-geological conditions or water balance due to lack of equipment and significant change in scope once seeing the actual field conditions. Some relevant data is presented with reference to previous studies.

## 1.5. Frame of Reference

Orongo village became the focus of this field study since it was identified as the location for a Lake Victoria region pilot project by Engineers Without Borders (EWB) Sweden. The initiators were familiar with the region and had an established local contact network. The proposed "Springs of Life" project aimed to establish a sustainable technology and environmental training centre, experimenting with and demonstrating different approaches towards better utilization of natural resources and provision of basic needs that could raise the community's standard of living. Improving water supply and treatment was one of the fundamental aspects requiring pre-study. While this thesis serves as a pre-study for EWB

Sweden, Orongo is representative of other rural villages, so the approach, findings, and recommendations should be relevant across the Lake Victoria region.

## 1.6. Research Questions

The Orongo location and awareness of need for water related improvements were established upon the community's contact with EWB Sweden. Broad issues were presented to EWB, but it was necessary that specific problems were investigated further. The line of thinking that motivated this thesis can be described in four main questions:

What are the village problems?
Background investigation required identifying the most significant issues facing the village. What are the health, cultural, political, and socio-economic conditions that need to be considered?

Which problems are water-related?
What is currently the situation for the drinking sources and treatment used? How does one go about assessing the water resources available, quantifying and characterizing the way the resources are used? How is health linked to water?

Where does the contamination come from?
A "catchment to consumer" approach attempts to identify and assess the contamination risk factors along all points in the water chain, from upstream catchment area, water points, treatment process, distribution and storage, to household usage habits. What are the information requirements to getting a good understanding of the nature and extent of supply and / or quality problems, and factors affecting the quality?

What can be done?
What supply and treatment methods are appropriate within the context of Orongo's social patterns and economic realities, based upon findings from the water assessment? What are some low cost and simple methods would provide safe drinking water in all areas of the village, all year-round? What methods can be adopted from other communities or NGO projects, either locally or internationally?

See Appendix A, Figures A.1 and A.2 for Flow Chart Overview of Thesis Structure

# 2. METHODS AND APPROACH

Fieldwork and data collection was carried out over a period of 10 weeks from November 2003 until January 2004, in Orongo village and the Kenyan Lake Victoria area. Local methods of supply and household water treatment were investigated and existing technical information gathered. Information was collected about the catchment and assessment made of the conditions and current status of water resources. Subsequent data evaluation and writing was done in Stockholm.

## 2.1. Village and Water Point Survey

Visits to Orongo were made on numerous occasions to collect information about the community, water handling practices, and status of water resources. Access was most feasible by bicycle from Kisumu 6 km away, since village paths were at times too muddy to pass with a car. The survey involved trying to find and sketch the location of all significant water sources; wells, boreholes, and streams, with details noted of the immediate and surrounding area conditions. Communal buildings with significant roof areas such as churches and schools, and main walking routes were also identified. Unfortunately no aerial photos or maps have been found to provide accurate locations of village structures and water points. Water point status was determined by visual inspection, talking to users and local well attendants. For the sanitation survey, an "Inventory of Existing and Constructed Water Collection Points" template from DHV Consulting Engineers (1987) was followed, as in Appendix C, Table C2.

## 2.2. Interviews

The "snowballing technique"' was used to track down required information. The Snowballing technique refers to the strategy where the interviewees are asked to refer persons and organisations that are considered relevant, and could give some additional data or verify some points. (Fadeeva, 2004)

Information regarding social, cultural, and some economic and health aspects was collected during an initial community meeting with residents of Orongo, then by subsequent informal interviews within the village and in neighbouring areas around the Winam Gulf. This was through spontaneous conversations with friends made, the family that I had lived with, and acquaintances met; informal face to face interviews with officers in various divisional, district, and provincial offices; environmental and water resource departments; conservation agencies; and NGOs.

## 2.3. Source Data and Local Literature

Economic data, health, and standard of living statistics were collected from Kenya Housing and Population Census reports and the Kisumu District Development Office. Information regarding local research on environmental pressures, Lake Victoria land management, water pollution, land use, ecology, technical surveys, etc, was mostly collected from documents at the libraries of KMFRI, LBDA, and ICRAF. See Appendix B.5 for abbreviation descriptions. Other technical reports, textbooks, scientific publications in both print and from the internet provided additional information.

## 2.4. Water Sampling and Analysis

Analyst services were hired from the Ministry of Water Resources in Kisumu. Well water samples were collected during a morning, and then all measurements were conducted in the lab beginning 2 to 5 hours after water was initially bottled.

The microbiological parameters tested were total (TC) and faecal coliforms (FC) using the membrane filtration (MF) method. The MF procedure used a lactose agar medium and incubation temperature of at 37°C and 44°C respectively. After 18-24 hours, the samples were ready for analysis. The TC test detects any of a large group of bacteria that may or may not be disease causing, but if there are large amounts of coliforms in the water, the chances are good that dangerous bacteria are present. The MF method gives 93% accuracy in differentiating between coliforms found in warm-blooded animal faeces and those from other environmental sources, however is not reliable in differentiating human and animal sources of pollution. (WHO, 2004 a)

The physical and chemical parameters tested include: pH, nitrite, chloride, fluoride, phosphate, iron, nitrogen as free ammonia ($NH_3$), carbon dioxide, alkalinity (as $CO_3^{2-}$ using phenolphthalein titration), oxygen absorbed (as PV, 4hrs at 27°C), total alkalinity (as $CaCO_3$), total and non-carbonate hardness (as $CaCO_3$), total dissolved solids, and electrical conductivity (at 25°C). It was not possible to test for any agrochemical related pollutants.

Two boreholes and four protected shallow wells were sampled. Unfortunately as finances did not permit more samples, this represents only 25-50% of all drinking sources. During the sample collection to peripheral areas of the village, numerous hand dug wells were newly discovered. These are often temporary sources so the locations change nearly every year as the water-logged ground collapses.

## 2.5. Catchment to Consumer Approach to Safe Water

Monitoring of various aspects of the supply chain as well as possible health effects requires the use of different applications and approaches. The WHO promotes two major initiatives that move to address this challenge: 1) the development of water safety plans, 2) the assessment of risk at all stages between catchment and consumer.

A proper Water Safety Plan involves establishing water quality targets based on public health protection and disease prevention, water supply chain system assessment, monitoring, management plans, and systematic independent verification. (OECD, 2003) This undertaking requires regional involvement and resources that are beyond the level of this thesis. However, significant elements are valuable tools and have been adopted for this rural village situation.

The HACCP program within a Water Safety Plan should identify the hazards and critical control points for all steps and activities in the overall plan from source water quality to the product at the point of consumer use, as outlined in Figure 5 below. (Sobsey, 2002)

Catchment awareness is the first step to understanding where some pollution originates. Other hazards and critical control points for household water treatment include choice of source water, type of treatment, methods of source water collection, and conditions of treated water storage and use. For each type of household water treatment and its application, elements of a water safety plan is developed based on WHO GDWQ and then adapted to the site-specific conditions in Orongo Village.

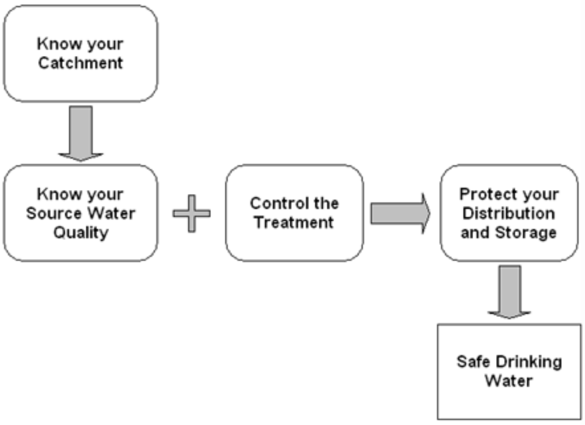

**Figure 5. Catchment to Consumer approach to risk management of safe drinking water.** (OECD, 2003)

Since it was not possible to tour the upstream catchment area, hazards were estimated from available maps, existing research reports, and informal interviews. During the well survey, every water point visited was assessed for its immediate and surrounding sanitary conditions. Well covers were opened to inspect the casing down as far as possible. Water storage, handling, and hygiene risk within the households are based upon personal observations and interviews, in combination with published findings from relevant studies.

## 2.6. Personal Reflections on Field Research Experience

It proved very difficult to find information, even while in the area. In advance of my study visit, not even a map of the district could be found, let alone of the village structure, geography, or water points. Even population estimates were a very rough guess; taken as a fraction of a larger census region figure, with approximately +/- 25% accuracy. So as a researcher aiming to assist an NGO in their project planning, the “pre-study” of the water resources was really beginning from zero knowledge.

Village specific technical data was largely not available. Information was from a scattered range of sources; independent research studies by various NGOs and government departments. These were difficult to hear about and track down as there was no central database, and those that had data often were protective of it. Some summary reports were collected, but raw, unaggregated sampling measurements were not found. Even the Lake Victoria Environmental Monitoring Program (LVEMP) efforts in monitoring the lake quality were limited in parameters, and did not manage for long with continuous data. Due to lack of funding, data depended largely upon analysis relating to specific projects and usually financed by outside agencies (Werimo, 2003). My approach therefore has been to derive maximum benefit from “second best” data.

Originally the aim was to research the aspects of Lake water as a drinking source, and evaluate small-scale treatment alternatives. Only once in the area did I find out that due to waterlogged conditions, everyone was living 2-3 km away from the shore, which made Lake water a last resort. Conditions in the village and proximity to the Winam Gulf were greatly underestimated before the study visit, therefore the scope had to be expanded to include groundwater and rainwater, and solutions limited to very low cost methods.

Also, once in Kenya, it became obvious that high technology methods would not be feasible alternatives for treatment or supply. Actually being there, seeing the situation, and getting to know people, drastically improved my understanding of poverty conditions and what it really means to live on less than “$1 a day”.

# 3. GENERAL REGION DESCRIPTION

## 3.1. Kenya Facts

The Republic of Kenya is home to approximately 32 million people (World Factbook, 2004) of mostly African background, but diverse by tribe and culture. The population is very unevenly distributed throughout the country, as the north and northeast regions are arid and quite inhospitable. Most Kenyans dwell in the central southern highlands where the climate is mild, and in the fertile south-western region.

The majority of the 80% rural population is mostly in the fertile areas and sustaining off of agriculture. Kenya has 32 major indigenous African groups, of which the seven largest constitute 84% of the population. (World Factbook, 2004) The tribe’s language is their native tongue; first to be learnt in the home. Kiswahili and English are both official and taught from primary school onwards. In the cities, most know English well enough to get by, but Kiswahili is the common language used extensively between tribes.

Kenya is a country in political and economic transition, relatively strong and diversified by continental standards, and making efforts to move away from a culture of corruption. The economy is still largely based on agriculture with exports chiefly of coffee and tea, but industry and tourism has grown in the past decades. Today the main problems with the economy are: negative commercial balance, huge external debt; power shortage; inefficient government control of key sectors; corruption; high (but declining) population growth rate; and unemployment (40% in 2001). (World Factbook, 2004) According to the World Bank, in 1992, 42% of the population was below the national poverty line; in 2002 it was 52%. There has been an obvious decline of living standards throughout most of the late 80's and 90's.

## 3.2. Lake Victoria Region

Lake Victoria is Africa's largest, and the world's third largest freshwater lake, with an approximate surface area of 68 000 km². It is actually an inland sea shared by Tanzania (51%), Uganda (43%), and Kenya (6%). The Kenyan Lake Victoria basin is a plateau located in the south-western corner of the country. It extends northward 120 km to Uganda's Mount Elgon (4321m) and northeast about 200 km to the Cherangani Hills at the western edge of the Rift Valley. Southward, the plateau is bordered at the east by the Mau escarpment and reaches the shores of Lake Victoria, 1134 m above sea level. (LVEMP, 2001)

The Kenyan waters of Lake Victoria lie just south of the equator between $0^0$ 4' S - $0^0$ 32'S and $34^0$ 13'E - $34^0$ 52'E, and cover an area of 3600 $km^2$. 1400 $km^2$ is comprised by the Winam Gulf (Nyanza Gulf)[1], which dominates in terms of shoreline and importance.

The Winam Gulf has a catchment area of about 12,300 $km^2$, (Lake Victoria has 181,000 $km^2$) which is drained, by 2 major rivers (Nyando and Sondu) and numerous smaller streams. (Kirugara & Nevejan, 1995) See the maps in Chapter 1.1. Since it is only 0.5% of total volume of the entire Lake Victoria, but receiving inflow from a large catchment (6.8% of total L. Victoria Basin), shallow, and has restricted flow circulation, the Winam Gulf is under significant pollutant, sedimentation, and eutrophication pressure.

The region is highly fertile and the holds the most productive agricultural lands - extremely valuable as 3/5 of Kenya's territory is non-productive and only 8.08 % is arable. (World Factbook, 2004) Approximately 2.5 - 3 million people live in the Winam basin. That means about 10 % of the total Kenya population lives in 2 % of the country's land area.

The northern shore of the Winam Gulf is rocky, with semi-encircling hills quickly rising to between 500 and 1000 m high. These hills continue in a horseshoe manner around the Gulf, but then towards the east veer away from the lake. Along the shores, soils are thin and vegetation occurs in quantities only along seasonal watercourses. The south-western portion is constituted of steeply sloping volcanic Gwasi hills as well as the southeast area around Homa hills. The southern shore is also very flat with some swamp areas bordering the Lake and watercourses, however, west towards Homa Bay, the topography becomes spotted with unique hills a few hundred meters in height popping up out of the plain.

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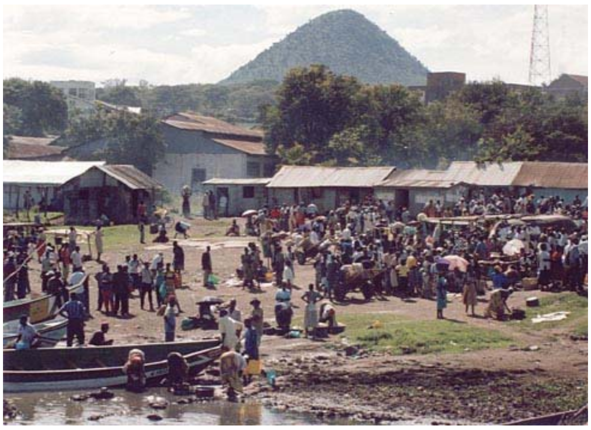
[1] The local name Nyanza means lake in Kiswahili



**Picture 1. Homa Bay market and hills**

**Picture 2. Kisumu, Kano Plain, Nandi Escarpment**

The low-lying Kano plain extends about 20-30 km from the eastern shore before it reaches the escarpment, dominated by marsh areas such as the Nyando swamp. Most of the swamp areas of the watershed exist in Kano, a flood plain previously under the lake. One of the major rivers, Nyando, bifurcates into stream that gets filtered through papyrus-dominated vegetation at the mouth. Portions are encroached to the north and northeast of the river mouth with large-scale rice irrigation schemes. (LVEMP, 2001)

# 4. ORONGO CASE STUDY AREA AND CONTEXT CONDITIONS

## 4.1. Village Location

Orongo village is located in the southeast part Kisumu District, which forms part of Nyanza Province. It lies in the Kano Plain, an extensive alluvial tract that extends from the Nyanza Gulf in an eastward direction. Orongo is located approximately 6 km southeast of Kisumu city, towards the lake off the Kisumu-Nairobi highway, in a 10 $km^2$ area characterized by homesteads, pastures, and sustenance plots. The village area is bound to the north 0.5 km past Buoye School, to the east by Luanda stream, to the west by Aguya stream, and to the south by Nyandiwa beach and the Winam Gulf.

## 4.2. Population and Demographics

In Kenya the population has doubled since 1979 and tripled since 1969, representing a growth rate of 3.3% annually to 1999. The fertility rate is also still high (4.6 / woman, 1995-2000). Compare to Sweden over the same periods, with a fertility rate of 1.5 and population growth rate of 0.3. (UNDP, 2001) Kisumu district population is still rapidly growing at average rate of 2% per annum, though the trend has slowed slightly in the 90's due to continued fall in fertility and rise in mortality from HIV/Aids coupled with deterioration of health care and other basic services. Reflecting this trend, the size of households has decreased from 5 to 4.4 over the period 1989-99. (Central Bureau of Statistics, 2001) The high population growth rate is not beneficial socially or economically. Increasing demands are placed on all types of resources to meet the need for basic services in terms of food, health, education, shelter, water, etc. The net effect is a decrease in the resources available for improving the standard of living of the people.

According to 1999 census data, Nyanza Province had 90% of the population living in rural areas, and Kenya overall 81%. Compare this to Sweden with only 15% of the population living rurally outside "localities". (Statistiska Centralbyrån, 2000) Orongo has about 3000 rural inhabitants, with most homes concentrated in three areas. See map Figure 4, Chapter 1.1. Approximately 45% live in the area of Orongo School, 30 % north near Buoye School, and 25% in the southeast corner near Luanda stream and Nyaimbo School, which is roughly represented by the school sizes, 450 students, 350, and 300 respectively. With about half of community land uninhabited marsh, the effective density is about 600 persons per km$^2$. This is higher than the Nyanza average of 350 / km$^2$, and magnitudes greater than in Sweden where the rural population density is only 3.5 inhabitants per km$^2$.

## 4.3. Political Organisation

The Kenyan system of government has 6 administrative levels. Orongo is located as follows:
Province – Nyanza
District – Kisumu
Division – Winam
Location – East Kolwa
Sub-location – Buoye
Village – Orongo

The Winam Gulf catchment area lies in the administrative region corresponding to the Nyanza, Western, and Rift Valley provinces. Vihiga is in Western province, while Nandi, Bomet, Kericho, and Nakuru (NE side of Bomet) lie in Rift Valley province. (Okotto, 2004)

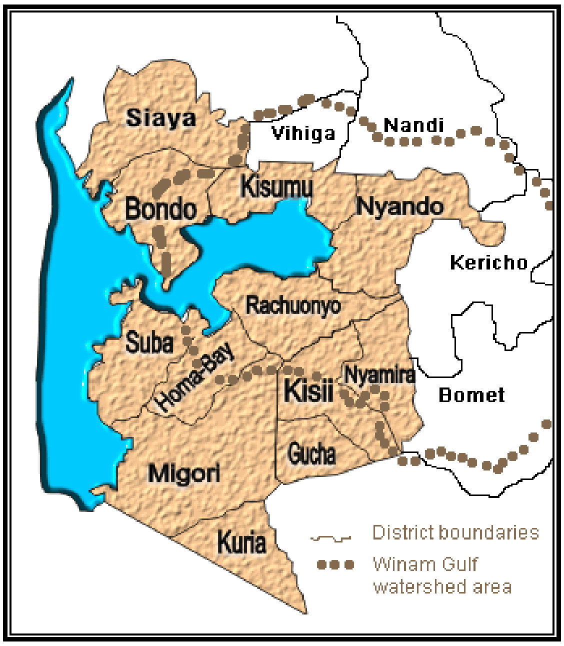


**Figure 6. Districts of Nyanza Province, and other districts within Winam Gulf watershed**

## 4.4. Transport, Communication, Infrastructure, and Housing

Infrastructure is not very well developed in Orongo. There are three schools, eight churches, and a central marketplace with a flourmill, but no piped water or electricity network. Nyanza as a region is below the national average in this regard, with less than 45% of households (HH) in rural areas having clean and safe water access (piped, borehole, or protected well), compared to 80% in urban areas. Access to electricity is very low; in 1998 it was less than 12% of all HH in Kenya (WWAP, 2003). According to the 1999 Population and Housing Census, only 4.2% of rural HH have electricity and less than 0.4% utilize solar energy, while 87% rely upon paraffin for lighting and 94% rely upon firewood and charcoal for cooking. See Appendix F for further statistics. Only a fractional percentage of Orongo residents have investments such as a generator or rain catchment tank system. In terms of communications, there is no wired network, but mobile coverage does reach the village.

Road access from the Kisumu-Nairobi highway consists of a 3-5m wide black cotton soil track that leads up to the market place (roughly the centre of the village) and slightly further to Orongo School. Elsewhere the paths are even narrower and used primarily by foot and bicycle. Since the land is flat and much open pasture, there is access to most areas while the ground is dry. However there is no improved road infrastructure; none of the paths or roads are drained properly nor contain any gravel foundation. Due to the high level of clay in the soil, all trails, and even the 1.5 km main track from the highway, become impassable for vehicles and bicycles after even moderate rain. The Nyandiwa beach on the Winam Gulf is 2 - 3 km from the village, and the way is usually inaccessible beyond the beginning of the swamp. An important community asset is unable to be utilized as there is no permanent road.

**Picture 3. Village road from highway**

**Picture 4. Traditional home under construction**

Most homesteads are built in the traditional way. Each house consists of a square framework of poles, carefully plastered with mud, with opening for doors and windows. See Picture 4 above. The outside walls are often decorated in earth colours. The pointed thatched roof keeps the house cool and airy under the hot afternoon sun while maintaining the warm temperatures during the night. It is estimated at least 95% of homes are traditional mud huts, however about 50% of these do have corrugated iron or tin roofs. A handful of families have homes with concrete foundations and walls.

## 4.5. Social Conditions

Organisation within the village is essential to know in terms of elders, decision-making, and working groups. Village structure for decision-making is centred in the management committee, headed by chiefs, which also serve as local administrative representatives. The members of the committee have to be ratified by the community. In regards to water issues of a large scale, the men usually have a greater say than the women. This can be explained in economic terms, as men own cash crops, while food crops are mainly a woman's responsibility. (IRC Water and Sanitation Centre, 1997)

However, water for household purposes is primarily a woman and child’s duty. It is estimated that an average of 3 hours a day is spent on the single task to fetching water for basic domestic needs. Increased accessibility and shorter walking distances to water points would allow engagement in other productive activities. The communal water points, however, provide a socially important meeting place where communication can be open between women.

Similarly, but on a family level, church services are at least a weekly occasion for socializing with more distant community members. They can also be strong platforms for mobilization and dissemination of information. Orongo is strongly Christian with at least 8 different churches being supported in the village. The churches are also involved in social assistance;

using member contributions for community services such as improving and maintaining water points.

Gender related disparity must be recognized which affects aspects such as ownership, control of family finances, and division of labour and duties. In Kenya, men and women have separate economic responsibilities. Water and firewood collection are seen as a women's responsibility.

The heads of household has been shifting towards women, with 50% in rural Nyanza compared to Kenyan average 37%. Women as key decision maker should be a positive statistic; however it is more commonly a result of widowing (that is double the national average) rather than migration of the men to towns in search of employment, therefore socio-economic status of the household is negatively affected.

Members of the Luo tribe predominantly inhabit the Kisumu area, including Orongo. Each group has its own dialect, customs, and taboos. Even within the same tribe, but different villages, practices can vary dramatically. The Luo tradition of polygamy affects family dynamics and must be considered even in the context of a water improvement. For example, if provisions are made to a family, it must be equal to each wife’s household to avoid conflict.

According to the 1999 Population and Housing Census, Nyanza Province has some of the highest rates of literacy in Kenya. About 75% of the population aged 5+ has completed at least some level of education, and Nyanza province is rated third highest with 31% achieving secondary schooling. National census figures show that school enrolment has been decreasing over the past 10 years, and illiteracy levels increasing, but Nyanza is still better off with only 2% that have never attended school compared to 9% nationally. Orongo also seems to prioritise education, with 3 schools providing at least primary levels (up to 8th grade) for about 1100 children in total.

## 4.6. Economic Climate

Understanding the economic conditions of the region, main sources of livelihood and income in the community assists in identifying causal factors that may lead to environmental pressure and degradation of resources. Kisumu city is a key port area and location of industrial plants such as plastics, flour and sugar mills, and a brewery. Fishing and boat building are also significant local industries. Economically the district relies heavily on the agricultural related activities. However, due to lack of market and dilapidated infrastructure no significant income is realized from these activities. The roads leading to the beaches and from farms to the factories are in poor repair and often inaccessible. (NEMA, 2003)

Agriculture in Nyanza, which is the source of livelihood of about 90% of the population, can be classified in two types. The first one represents the heritage of the large colonial plantations, devoted to the culture of coffee, tea, cotton, sugarcane, potatoes, tobacco, wheat, peanuts, sisal, and sesame. Coffee and tea were the main crops produced for export in 1998. (Canadian Consulate, 2003) The second type, but dominant source of livelihood, is subsistence farming performed by local owners in small plots. Farmers in Nyanza Province grow millet, maize, beans, sorghum, cassava, and bananas as basic foods.

Poverty cuts across all sectors of development. In a poverty assessment report for Kisumu district in May 2000, it was established that 53% of the population was living below the national poverty line[2] (urban 1645.03 and rural 1123.90 KES / month)[3], and increasing. In the sub-division that includes Orongo village, 70% are below the poverty line (CBS, 2003). The main causes of poverty in the district can be identified as environmental, economic, HIV/Aids and socio-cultural factors. Inadequate and unreliable rainfall pattern has immensely affected agricultural activities. On the other hand during the rainy season, persistent flooding of the major rivers in the low-lying areas destroy crops and causes water-borne diseases in both people and livestock. (NEMA, 2003) Orongo village is especially affected by flooding.

Minimum wage according to the Kenya Bureau of Statistics is 2822 KES per month (135 per day) within Kisumu municipality, and 1540 per month (78 KES / day) in "other areas". Assuming a 5-day workweek, the latter is roughly equivalent to $1 US per day. However, from discussion with local farm owners and workers, the average farm labourer salary is only 50 KES per 5-hour workday. So at 300 workdays a year, that means about 1250 per month; well below the "$1 / day" internationally recognized poverty threshold[4]. The lower income group, as defined by the Kisumu District government, is 699-1999 KES / month.

Villagers of Orongo have only marginal income generation possibilities (less than $1 per day). Though the soil is fertile at the lowlands, families manage to cultivate only one rain-fed crop per year on land that is not as affected by flooding during the two rain seasons per year. The lowland area forms a trough of low rainfall, the second, "short" rains have low reliability and distributed over a long period, making cultivation of second crops difficult.

Most of the lands are owned individually and registered with land parcel numbers and title deeds, which is a good incentive for long-term investment. The inhabitants claim wetlands but some are registered under trust of the county Council. Communal use of land is also common, particularly nearer the lakeshore where livestock is grazed. Small farms range from 0.2 – 12 hectares, and the average size of a plot is 2 ha. Agriculture furnishes the main source of income, through sale of farm produce, casual farm work, and sale of livestock. (Rabour, 2001)

Economic activities in the village also include papyrus mat weaving and other small home enterprises carried out by women's groups. Clay minerals are available in Kano plains, and building sands are available in rivers like Nyamasaria and Luanda stream. These are used in ceramics, pottery handcrafts, and house construction. Fishing takes place, but is not as prevalent as in other lakeside communities, partially due to 3 km of marshland limiting access to only foot transport. The community's overall poverty hinders meaningful contributions towards development efforts. However the "harambee", or self-help spirit, is well understood in rural areas. People contribute in terms of labour or cash if they can, towards schools, churches, rural road construction and cattle dips.

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[2] National estimates are based on population-weighted subgroup estimates from household surveys. Definitions of poverty vary considerably among nations. This 1997 adult-equivalent poverty line includes the Ministry of Finance and Planning 1994 food poverty line (874.72 KES urban and 702.99 KES for rural areas per adult/month), plus mean non-food consumption and inflation adjustment. (Geda et al, 2001)

[3] the currency exchange rate at Jan '04 was 10 KES/ 1 SEK, and 78 KES/ $1 US

[4] the 'income-level' which allows individuals or households to meet what experts define as "their needs". $1 a day at 1985 international prices (equivalent to $1.08 at 1993 international prices), adjusted for purchasing power parity. $0.53 / day per capita has been quoted as the rural poverty line in Kenya. However by being income based, poverty lines can be a very inaccurate reference point, insufficiently adjusting for local cost of living, and not recognizing "hidden income" such as water or education. Many are simply set between 1.15 to 1.3 times the cost of a 'minimum food basket'. See SEEP Network (2004) for calculation explanation.

## 4.7. Community Health

### 4.7.1. Identification and Basic Classification of Water-related Disease

Water related disease may be classified as two types: infections caused by a biological agent (pathogen), and water-chemistry related diseases (such as fluorosis), which in developing countries are totally overshadowed by the infections. (Falkenmark, 1983)

Information on the most pressing health concerns assist in providing a picture of the overall well being of a community. Especially the very young, old and those suffering from immune deficiency-related disease such as malnutrition or AIDS, are at a significant risk of infection. An overview of disease prevalence and statistics on child and infant mortality provides a good benchmark. The general status can be collected from local studies and census information, or estimated by field observation of risk conditions and interview feedback. Prevalence of waterborne disease can give general insight into the status of drinking water supply, hygiene, sanitation, and safe water handling practice. A detailed study of health care records would aim to establish the proportion of a community with disease related to water supply. The conditions in Table 1 are most relevant to research. See Appendix B.1 for more detail.

**Table 1. Types of water related disease**

| Faecal-Oral Microbial Infection[1, 2] | Skin & Eye Infections[2] | Parasitic Worms |
|---|---|---|
| Cholera bacteria | Trachoma | Intestinal helminths [1, 2] |
| Bacillary & Amoebic dysenteries | Conjunctivitis | Schistosomiasis [3] |
| Gastroenteritis virus | Skin ulcers | Guinea worm [3] |
| Enterovirus infections (some) | | |
| Diarrhoeal disease | | |
| Rotavirus infection | | **Insect Vectors** |
| Enteropathogenic + toxigenic | | Yellow fever |
| E-coli bacteria infection | | Dengue fever |
| Giardiasis protozoa | | Malaria |
| Typhoid fever bacteria | | |
| Infectious Hepatitis virus | | |

**1** - *Water–bourne*: transmitted by any route that permits faecal material to reach the mouth.
**2** – *Water-scarce or water-washed*: quantity of water important as hygiene inhibits infection.
**3** – *Water-based mechanisms*: pathogens have an intermediate aquatic host, such as a snail.
**4** – *Water-related insect vectors*: transmission by insects that breed in water or bite near water. (Adapted from Cairncross et al, 1981)

### 4.7.2. Microbial Pathways in Water

Many diseases may be transmitted via a faecal-oral route, occurring when human faecal matter is ingested through drinking contaminated water or eating contaminated food. Water is an important medium for transmitting disease as contamination with excreta can lead to ingestion of faecal matter (see infection cycle Figure 7). The likelihood of acquiring a waterborne infection increases with the level of contamination by pathogenic micro-organisms. However, the relationship is not necessarily a simple one and depends very much on factors such as infectious dose and host susceptibility. (WHO, 2004 b)

The faecal - oral route includes several and multiple routes to infection as summarized in Figure 7 below.

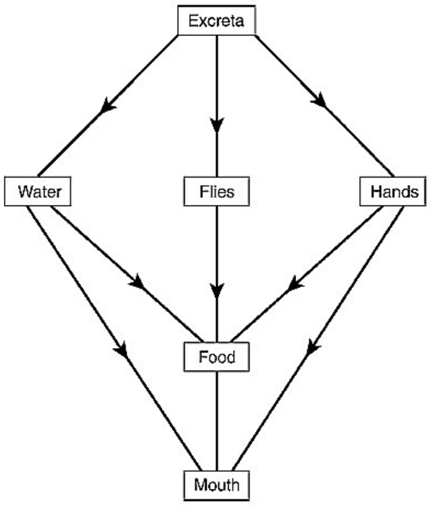


**Figure 7. Faecal - oral disease transmission** (WHO, 2004 b)

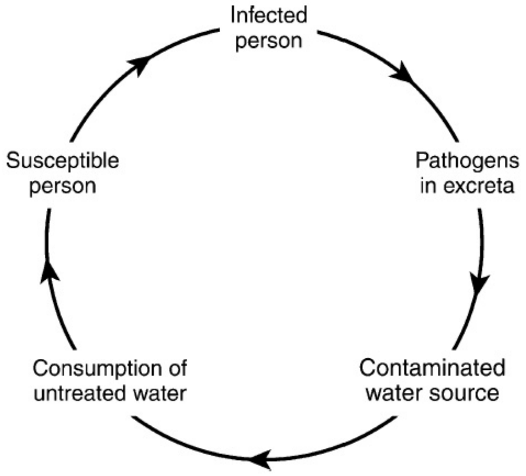


**Figure 8. Classical Waterborne Infection Cycle** (Tebbutt, T.H.Y., 1992)

The quality of water, though not the sole determinant does have a great influence on public health. Poor microbiological quality is likely to lead to outbreaks of infectious water-related diseases and may causes serious epidemics to occur. Chemical water quality is generally of lower importance as the impacts on health tend to be chronic long-term effects and time is available to take remedial action. Acute effects may be encountered where major pollution event has occurred or where levels of certain chemicals are high from natural sources, such as fluoride, or anthropogenic sources, such as nitrate. (WHO, 2004 b)

Improved water supply may reduce disease through availability and quantities used, changes in the water quality, and in contact with water bodies containing intermediate hosts. By looking at the disease pattern of the study area, one can obtain indications of the types of water improvements most urgently needed, of the public health importance of water-related disease, and of any hazards generated by the current supplies. One of the few general conclusions that may be drawn about drinking-water quality is that *if faecally-derived pathogens are not present, then endemic or epidemic waterborne disease will not occur*. (WHO, 2004 b)

However eliminating all pathogens is not realistic, and therefore it is important to note that just supplying clean water is not guaranteed to make people healthier. Even if the drinking water is safe at the source, it may be contaminated afterwards. The complexity of routes also demonstrates the importance of various aspects of hygiene as complementary actions to water quality improvements. Individual people have to be aware of how to protect themselves at home and when away. As indicated by Table 2 below, programs need to integrate water quality improvements with improvements in water availability, sanitation, and hygiene education to achieve the significant health benefits in preventing infections.

**Table 2. Relationship between infections and importance of preventative measures**

| INFECTIONS | *Water Quality* | *Water Availability* | *Safe Human Excreta Disposal* | *Personal and Domestic Hygiene* | *Drainage* | *Food Hygiene* | **Public Health Importance** |
|---|---|---|---|---|---|---|---|
| 1. Diarrhoea diseases and enteric fevers: | | | | | | | |
| Viral Agents | ▓ | ▥ | ▓ | ▥ | ░ | ▓ | ▥ |
| Bacterial Agents | ▥ | ▥ | ▓ | ▥ | ░ | ▥ | ▥ |
| Protozoal Agents | ▒ | ▥ | ▓ | ▥ | ░ | ▓ | ▓ |
| 2. Hepatitis A | ▒ | ▥ | ▓ | ▥ | ░ | ▒ | ▥ |
| 3. Worms with no intermediate host: | | | | | | | |
| Ascaris, Trichuris | ▒ | ▒ | ▥ | ▒ | ▒ | ▓ | ▓ |
| Hookworms | ▒ | ▒ | ▥ | ▒ | ░ | ░ | ▥ |
| 4. Beef & Pork Tapeworms | ░ | ▒ | ▥ | ▒ | ░ | ▥ | ▓ |
| 5. Worm with intermediate aquatic stages: | | | | | | | |
| Schistosomiasis (Bilzharzia) | ▒ | ▒ | ▥ | ▒ | ░ | ░ | ▥ |
| Guinea worm | ▥ | ░ | ░ | ░ | ░ | ░ | ▓ |
| 6. Skin, eye, louse-bourne infections | ░ | ▥ | ░ | ▥ | ░ | ░ | ▓ |
| 7. Insect vector spread: | | | | | | | |
| Malaria | ░ | ░ | ░ | ░ | ▒ | ░ | ▥ |
| Yellow fever and Dengue | ░ | ░ | ░ | ░ | ▒ | ░ | ▥ |

░ = no importance
▒ = little importance
▓ = moderate importance
▥ = great importance

Adapted from Falkenmark, 1982 and Boot and Cairncross, 1993

### 4.7.3. Fluorosis

Ingestion of excess fluoride, most commonly in drinking-water, can cause fluorosis which affects the teeth and bones. Moderate amounts lead to dental effects such as staining and pitting (until 6 years of age), but long-term ingestion of large amounts can lead to potentially severe skeletal problems. Greater than 1.5 mg/l may cause mottled teeth, and at higher concentrations than 3 mg/l fluoride can cause chronic toxicity and cause bone problems beginning with stiffness and pain in the joints (WHO, 2004 b). Severe cases of crippling fluorosis have been detected in individuals exposed to fluoride levels from 10-40 mg/l (DeZuane, 1997). Paradoxically, trace amounts actually strengthen the teeth.

The United Nations estimates that the health impact of naturally occurring fluoride is more widespread than arsenic, however much less publicized (WWAP, 2003). Moderate-level chronic exposure, above 1.5 mg/l (WHO GV and Kenya standard), commonly affects a number of areas including the Rift valley of East Africa. The acceptable concentration of fluoride in water is in part related to climate, as in warmer climates the quantities of water consumed are higher thus leading to a greater risk of fluoride related problems as overall intake increases. A person's diet, general state of health, and the body's ability to dispose of fluoride, all affect how the exposure manifests itself. (WHO, 2004 b)

### 4.7.4. Health Conditions in Orongo Village and Area

Previous regional health surveys have revealed that water borne and water related diseases such as cholera, typhoid, bilharzias, amoeba parasite conditions, hookworm and dysentery are very common in the shoreline settlements (CBS, 2002). Diarrhoeal disease is related to 40% of under-five child mortality worldwide (WHO, 2004 b), and according to residents is an ongoing problem in Orongo. Diarrhoea also leads to frequent illness and impaired growth in children, as do skin and eye infections, and parasitic worms.

Orongo has no regulated, piped, or purified water supply system and most of the sources are inadequately protected and vulnerable to faecal contamination from livestock and residents. Sanitation is provided by open bush and pit latrine, with proximity to the water resources in many cases a matter of concern. Seasonal flooding exacerbates the problems, and during extreme years, knee-deep water has provided conditions for disease. Cases of cholera appear every year and the most recent outbreak occurred during 1997/98 El Niño flooding.

The health situation in Nyanza is much worse than the national average. With 195 deaths / 1000 live births (rural areas 211 / 1000), children in Nyanza province are the most at risk in Kenya; nearly 4 times more likely to die by age 5 than in Central Province. Life expectancy is 49 years. (CBS, 2002) National census data in Table 3 below, has related child mortality to source of water and type of sewage disposal.

**Table 3. Child mortality by main source of water and sewage disposal (per 1000)**

| | | | | | |
|---|---|---|---|---|---|
| Lake Victoria | 263 | River | 164 | Bush | 157 |
| Pond | 191 | Well | 155 | Bucket latrine | 116 |
| Borehole | 177 | Tank / jabia | 117 | Pit latrine | 115 |
| Dam | 165 | Piped | 116 | Septic tank | 88 |
| | | | | Main sewer | 88 |

(CBS, 2002)

Lake water source and open bush human waste disposal are associated with the highest levels of child mortality. However, care should be taken in drawing conclusions from these figures, as many other factors could also be involved. It is strange that boreholes would be more highly associated with morbidity than river water. Perhaps people see borehole water as clear, think it is completely safe, and take fewer precautions. Regardless, the overall child mortality levels of 1 in 5 are staggering and water and sanitation are significant factors. Compare this to Sweden with only 4 deaths / 1000, and life expectancy of 78 years (UNDP, 2001).

Although microbiologically related diseases are the most important health concern in Orongo, fluorosis likely affects people to some degree. A study in Nakuru district, about 100km from Orongo, found residents consuming ground and surface water with levels of fluoride of between 2.5 and 8.5mg/l, resulting in high incidences of dental fluorosis, of up to 48%. Residents were bothered by the fluorosis, although most did not know the cause, or remedies for the problem. (Moturi et al, 2001)

# 5. IDENTIFICATION OF HAZARDS FROM ORONGO CATCHMENT AREA

The "catchment to consumer" approach involves identifying all significant contamination risk factors – those upstream, around the village and water points, and in the household. Information on sources of pollution in the catchment area gives both an indication of the level of contamination that may be expected and potential risk events (i.e. heavy rainfall flooding latrines and running into wells). A catchment survey aids in the selection for the best abstraction sites, yields information on priority contaminants to test for, and identifies potential protection measures. Addressing and controlling the sources of pollution is a more sustainable measure to improving water quality than only installing treatment barriers.

The approximate watershed area feeding the streams that eventually flow through Orongo village is identified in Figure 9 below. The catchment is approximately 520 km$^2$.

Beginning north of the Nandi Escarpment in the highlands, it stretches about 25 km east to west and at altitudes from 1500m to 1800m. The catchment funnels southward, about 34 km at its longest, until it reaches a 6 km section of shore on the Winam Gulf at 1134m.

Two streams flank Orongo village, the Nyamasaria on its west, and the Luanda on its eastern border. The Luanda flows mainly from the Kibos river, but also fed by the Lielango and Nyangeta, which about 12 km upstream flow through major commercial plantations in the middle of the sub-catchment. In the northeast, the Awach river feeds both the Kibos and Nyamasaria. The topography roughly flows from northeast to southwest.

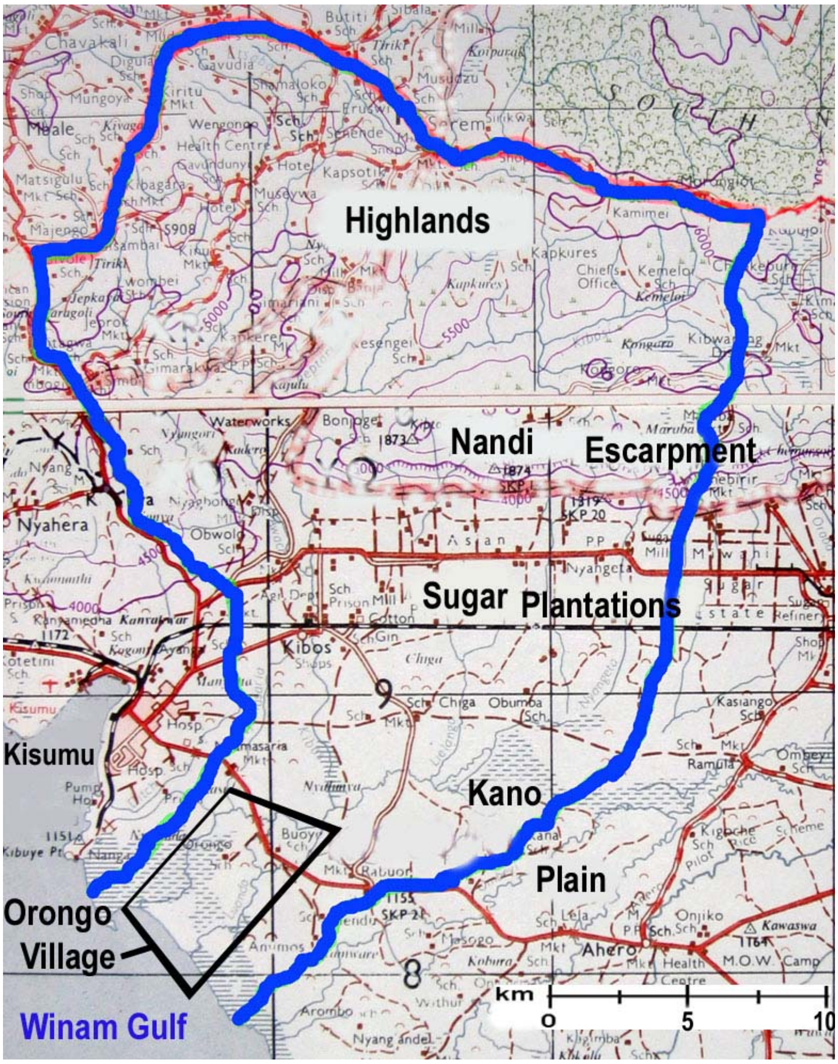
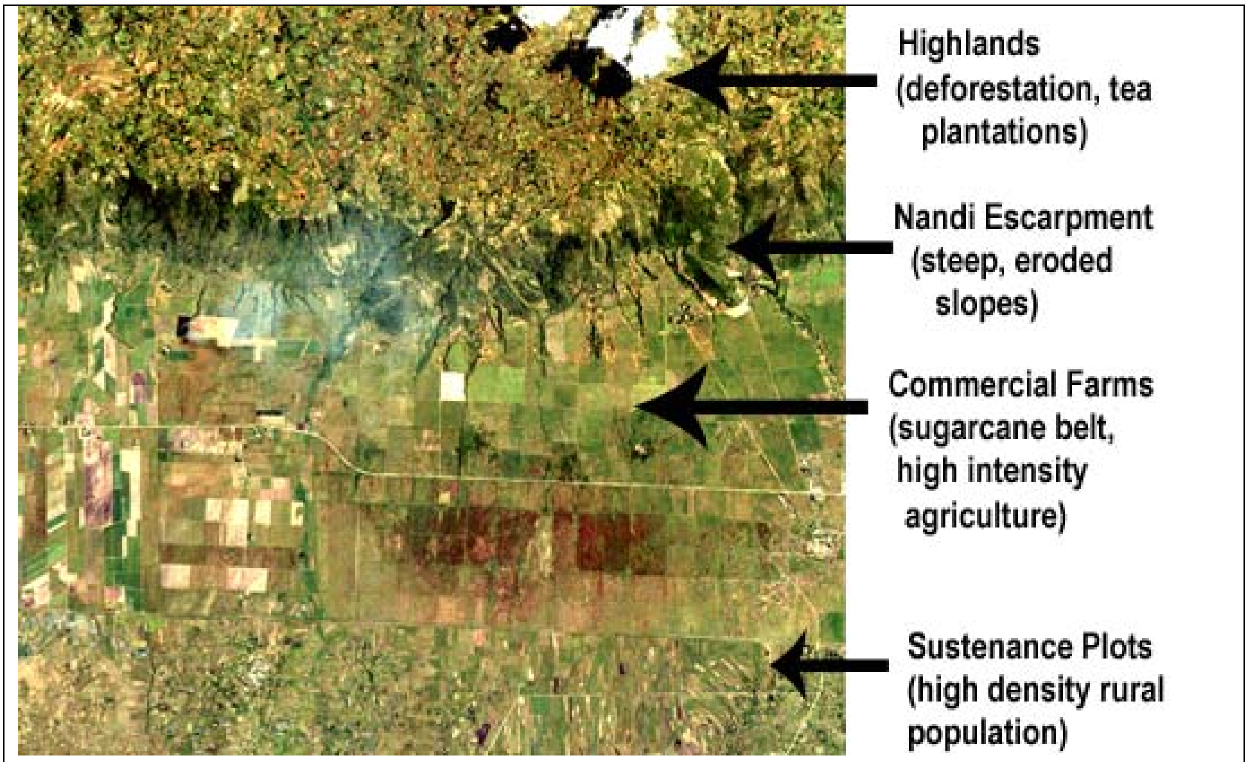
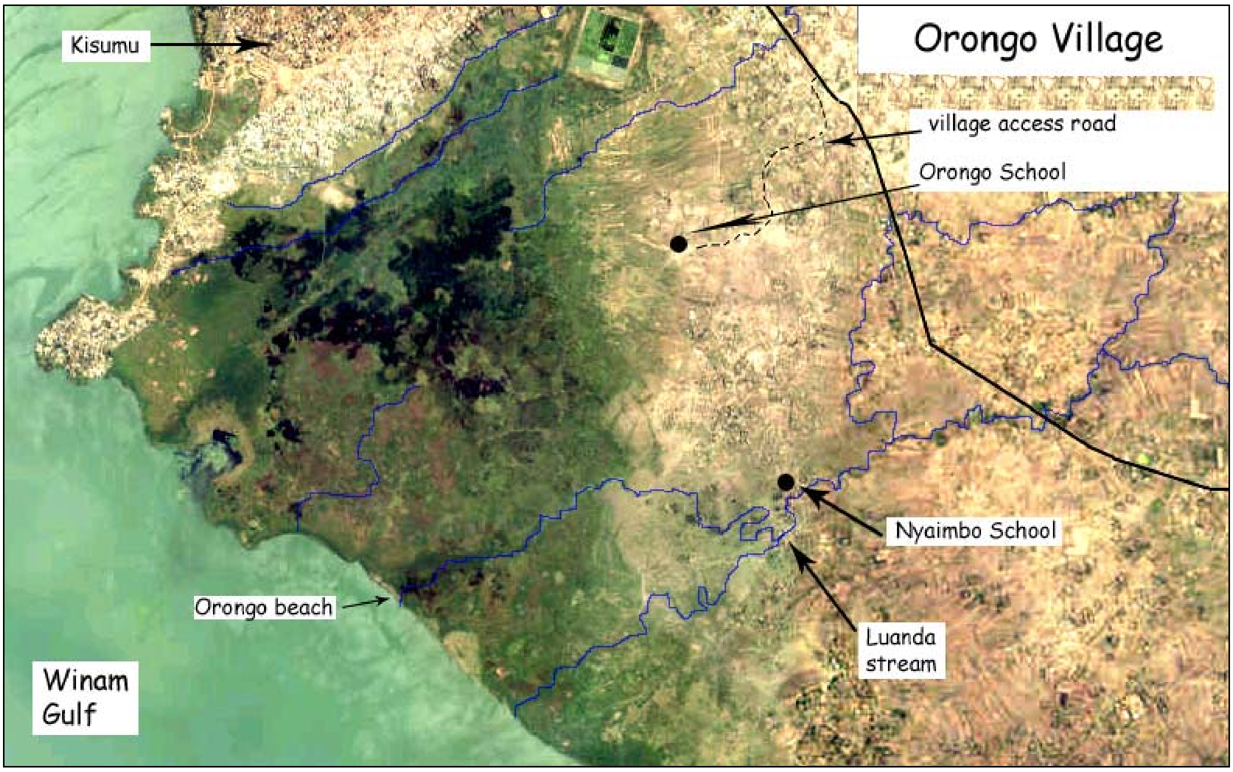


**Figure 9. Orongo Village watershed** (Survey of Kenya, 1983)

Comparing Figure 9 with Picture 5, it can be seen that the satellite image below captures a view of the centre of the catchment. Large-scale commercial estates can be seen just south of the Escarpment's steep slopes. Further southward of the sugar cane plantations and commercial estates, sustenance farming and a dense rural population extend toward the Gulf.



**Picture 5. Satellite image shows centre of watershed and main landscape features.** (Terrafly, 2002)



**Picture 6. Orongo Village prominent physical features** (Source: Terrafly, 2002)

The satellite image Picture 6 represents natural earth tones: Dark (green) = marsh / grassland vegetation; medium shades (brown) = cultivated land; speckled areas = high-density settlement; bright areas = barren land; black = shallow surface water.

## 5.1. Natural Factors

### 5.1.1. Topography, Slope, and Flood Area

Knowledge of the topography, land use, vegetation, slope, rainfall intensity, and soil type can be used to identify areas of high erosion risk. Ideally, remotely sensed data and Geographical Information Systems is available to model rates of erosion and predict sedimentation or consequences of human activities. In the absence of GIS, some risks can still be identified.

The altitude varies from 1134 m at the lakeshore, up to 1800 m in the highlands (see Figure 9, Orongo Village watershed). Slopes are steep in the Nandi Escarpment 20-25 km northeast, and deforestation has worsened erosion that affects watercourses entering Orongo.

Towards the Kano Plain, the land quickly becomes extremely flat. The entire area has characteristics typical of a lowland floodplain with minimal slope. Much of the area southeast, adjacent to the lake and 2-3 km inland, consists of marshland. The significant marsh area is obvious from Picture 6 above. Taken during a typically dry time of year, still nearly 50 % of the village land is showing green vegetation indicative of water-logged ground.

Surface retention of water generally lasts for 2-4 days but marshlands remain wet for 8 to 10 months. At the time of a field survey in November 2003, the land was fairly dry and hence accessible up to about 800 m beyond Orongo School. The average slope the first 400 m from the school is about 0.25%, but the next 400 m (and average slope through the marsh) is roughly only 0.08%. Some parts of the road were below the average ground level.
The drainage network in the agricultural land and around homesteads consisted of mostly random channels across and along the direction of the general slope. (PIU, 2003)

Approximately forty years ago the marshland area was not as extensive as it is today. Since completion of the Ugandan Owen Falls dam in 1954 across the Victoria (White) Nile, discharge of Lake Victoria has been strictly regulated, leaving all lowlands inhabitants vulnerable. Seasons of heavy rainfall in the early 1960s resulted in a rise in water level of 2 m and extensive shore flooding, forcing residents and cultivation to move inland. (Klohn and Andjelic, 2004)

Land-lake breeze creates daily mean displacement of 15 cm, while a mean displacement of 50 cm occurs on a yearly basis. (Kirugara & Nevejan, 1995) The Lake has experienced fluctuations of about 3 m; nearly +1.7 m during 1997/98 El Ninõ rains. (GIWA, 2004) According to residents, flooding submerged most of Orongo in knee-deep water. Many people had to take shelter in the higher ground churches and schools, while even the highway to Kisumu appeared like a bridge surrounded by water. Peak flood events induce high risk for surface water, well, and even borehole contamination, if pump bases are not properly sealed.

### 5.1.2. Meteorology and Weather Patterns

Climatic and seasonal variations such as heavy rainfall and droughts have a significant impact on the potential for peak contamination events. Kinetic energy of rainfall depends on the size of drops, intensity, and wind velocity. The impact of raindrops initiates loosening and detachment of soil particles, with erosive power significantly increased at an intensity of about 35 mm/hr (Thanh and Biswas, 1990). Tropical rainstorms that equal or exceed this erosion threshold are experienced in Kisumu. Rainfall and temperature distribution patterns, with pronounced wet and dry seasons, also accentuate soil erosion. During the dry season vegetation is reduced to a minimum with some topsoil lost due to wind erosion, and then significant damage is done at onset of first heavy rains.

The climate of the Winam Basin ranges from humid in the highlands with some of the wettest areas in the country, to semi-arid in the Kano plains. The upland is very heterogeneous and receives dissimilar rainfall, annually ranging between 900 and 2200 mm. The Kisumu area towards Orongo and the Kano Plains has the highest mean annual evaporation (about 2100mm) of the entire Lake Victoria catchment region. The annual rainfall-potential evaporation ratio is 50%-65%, and actual annual evaporation is estimated at 1200 mm. (DHV, 1987) Temperatures are high during the day and moderate at night, with annual highs of 31°C and lows of 17°C. Altitude is a major factor in variations in temperature between the different regions. At the shores of Lake Victoria climate is modulated by an altitude of about 1,135 m and by the moist winds coming from the Lake.

**Table 4. Climatic Conditions in the Nyanza Gulf Catchment Area (mean annual values)**

| | | |
|---|---|---|
| Rainfall (mm/yr): | 2134 (Kericho) | 1128 (Winam Kibos) |
| Rain days (days/yr): | 203 (Kericho) | 88 (Winam Kibos) |
| Temperature – max (°C): | 22,7 (Kericho) | 30.9 (Kisumu) |
| Temperature – min (°C): | 8,9 (Kericho) | 16,9 (Kisumu) |
| Sunshine (days/yr): | 78,1 (Kericho) | 99,3 (Kisumu) |
| Evaporation (mm/yr): | 1395 (Kericho) | 2290 (Kisumu) |

(adapted from Kirugara & Nevejan, 1995 and World Weather Information Service)

The conditions in Orongo are near the dry side, similar to neighbouring Kibos and Kisumu. Mean annual rainfall likely can vary from 900-1400mm, while the 20-year annual average for Kisumu is 1388 mm. Precipitation primarily occurs in 2 seasons; the long rains from March to May, and short rains from October to December. Precipitation is much greater in the highlands north and east of the Kano Plain, and streams like the Luanda receive peak flows after the long rains (when 70% of the annual precipitation is usually received).

### 5.1.3. Geology and Soil

Naturally occurring chemicals and minerals in combination with the soil leaching potential and hydrology, can lead to drinking water health risks. Soil composition, sedimentation and geological formation can affect the yield capacity of wells, water recharge, structural stability, as well as the water quality, i.e. radon, arsenic, fluoride.

According to a study of Winam Division by DHV Consulting Engineers (1987), the Orongo area contains geologically recent sediments of about 10-25 m deep, generally clayey, although sand can be found. The top 1.5-2.5 m is loam and silt, while about 2-6 m is a mixture of loam, silt and gravel. The shallow aquifer seems to be unconfined as they it generally found to be heavily contaminated by faecal coliforms. Alluvial Pleistocene deposits are silty, sandy, and clayey, occupying the zone from about 15-90 m. Groundwater occurs in intercalated thin sand, shell, and silt layers, and known to be saline in the swampy areas bordering the Winam Gulf. Tertiary volcanics appear to lie below 70-90m, indicating the bottom of the aquifer.

The quality of groundwater can be a problem in volcanic rocks, as high-fluoride groundwater is common in the rift valley regions of Kenya and Tanzania. The geology of Kenya makes it one of the countries in the world where fluoride occurs in highest concentrations, not only in rocks and soil, but also in surface and ground water. Waters with high levels of fluoride content are mostly found at the foot of high mountains and in areas where the sea has made geological deposits, allowing long contact time with fluoride-bearing minerals. However many other factors affect the concentration of fluoride in water, such as temperature, pH, and the nature and porosity of the rocks and soils over which they pass. (Gikunju, JK et al, 2002)

In the Kano plains are found histosols and gleysols commonly associated with swamps around the lakeshore. The fertile clay-loam soils are suitable for crop production and for irrigated farming. Soils of drier areas have higher content of montmorillonite clays, typical of the Orongo area (PIU, 2003). These black cotton soils of the plain are calcareous, ill-drained, plastic when wet, and crack deeply when dry. Paths become muddy and impassable with only a couple centimetres rainfall.

### 5.1.4. Wildlife and Nature

Found in the marsh area are a wide variety of birds and sometimes hippos. Large wild animals within the catchment are not a risk for microbial contamination, their population is scarce, and with dense settlement they rarely wander far into the village. Small rodents and birds could be of a concern to household storage and rainwater collection.

Plains area vegetation consists primarily of grasses, aloe vera, cactus, scattered thorny bushes, and trees including tamarind. Natural vegetation in the swamp consists mostly of common reeds, bull rushes, sedges, papyrus, water hyacinth, and an assortment of marshland weeds. The watercourse vegetation is not at all a hazard, but provides an important natural cleansing.

## 5.2. Human Use Factors

### 5.2.1. Development Intensity and Landuse Changes

Increasing population, an urbanizing catchment, and socio-economic activities have brought about overgrazing, deforestation, soil erosion, increased domestic waste discharges, greater use of pesticides and destruction of wetlands. These activities have result in pollution and excessive nutrient enrichment (eutrophication) in the surface waters. The World Bank has estimated the population growth at 4% in the riparian districts (LVEMP, 2004) and it is creating intense ecological and environmental pressures with significant competing interests on the region's natural resources.

The catchment can be divided into three distinct land-use zones that follow the altitude gradient.

A) Highlands: from the Nandi Escarpment and north about 12 km. Milder, wetter climate, and relatively thick vegetation as expected with high altitude. Wetlands as well as some rural population and sustenance agriculture, especially in the northeast corner. Some small scale tea growing, maize and horticulture exists.

B) Sugar belt: South of the Nandi Escarpment, between about 1300 and 1700 m, and in about a 9 km wide belt, is characterized by undulating hills interspersed with wide valleys and tea and sugar plantations. The large commercial blocks of land are visible in Picture 5, Chapter 5. Urban development becomes much more significant, especially in and around the town of Kibos. Industries such as sugar mills and tea factories are located in this region, spilling effluents into the watercourses.

C) Kano Plains: the southern third of the catchment consists of plateau tableland dominated by marsh areas, sustenance agriculture (millet, maize, cassava, bananas, and sorghum), and a dense concentration of rural settlement. The catchment in the west borders dense slum concentrations of Kisumu city (LVEMP, 2001). Areas of high population and significant land degradation exist upstream of Orongo. Marsh is prominent within Orongo village and indicative of the area's low-lying proximity to the Winam Gulf.

Most of the watershed is nearly continuously cropped, with no significant forest area. The steep slopes of the escarpments are being quickly de-vegetated for firewood, charcoal, and illegal farming. Anthropogenic activities are significantly worsening the quality and reliability of watercourses.

### 5.2.2. Agriculture

The Lake Victoria region holds some of the most agriculturally productive areas in the country with extensive use of agro-chemicals and has several major urban centres including Kisumu. Increased agricultural in-put has continued to endanger the environmental health of the lake and upstream tributaries. There is a clearly perceived risk relating to the inappropriate use and handling of agrochemicals, notably pesticides, some of which are very toxic and extremely long-lived. (Chege, 1995)

A study by LVEMP (2004) assessed the local use of agro-chemicals. The Nyando River drains through an area of intense agricultural activities (tea, maize, coffee, sugarcane farming, and livestock rearing on a commercial scale) before finally discharging into the Winam Gulf, about 20 km away from Orongo. The study found:

- Fertilizers, herbicides, insecticides, fungicides, and acaricides are commonly used.
- Fertilizers and herbicides are mainly used in maize, tea and sugarcane zones.
- Mostly organophosphates, but there are strong indications of banned organochlorines (lindane, aldrin, dieldrin, and DDT) still being used in the Lake Victoria basin.
- Most farmers are ignorant of the safe use and management of agrochemicals.
- High load of sediments is experienced due to high level of soil erosion, phosphorus and nitrogen from tea estates, and phosphates from domestic effluents.

The waterways entering Orongo village pass through similar upstream areas as the Nyando River, with exception of tea plantations, and similar contamination hazards can be suspected.

The Kibos River, which feeds directly to Luanda stream and Orongo village, also has a very high silt load and high nutrient levels. Widespread deforestation has lead to soil runoff coupled with agriculture runoff, which contains residues of chemicals from tea and sugarcane plantations in the Nandi Hills. Conversion of upstream wetlands into agricultural areas reduces sediment containment, capacity for self-purification, and flow control. The Kibos and Nyamasaria rivers have recently been experiencing frequent flash floods. (NEMA, 2003)

### 5.2.3. Erosion and Inadequate Buffer Zones

Deforestation, soil erosion, and failure of sediment traps are some of the factors that increase sediment and contaminant load to waterways. According to local research, 46% of the

Nyando river basin has experienced severe soil and physical erosion. (GIWA, 2004) The neighbouring Nyamasaria and Luanda basins can be assumed to have just as severe erosion.

Due to extensive deforestation of the lowland areas and a charcoal/wood fuel crisis, harvesting of trees has moved to more ecological fragile areas like hilltops, impacting negatively on soil and water sources. From observation it appears that the hills near Kisumu have only about 5% tree cover remaining, and 10 - 40% is barren rock. Due to the high gradient and thin topsoil cover, there is increased soil runoff leading to erosion and siltation.

The uncultivated areas between farm plots, surrounding the community, and marshland south of the homesteads are utilised as communal grazing lands. Grassland management is however, poorly controlled and land degradation is evident. Watering is done at any surface water source such as ground catchment, ditch or stream, and the herding through of cattle erodes the stream banks. A lack of protective dense vegetation buffer zones along watercourses, further deteriorated by watering cattle, contributes to the extreme turbidity. Silted runoff further degrades water quality as organic or chemical contaminants commonly bind to particles.

### 5.2.4. Human Access

Recreational activities, washing, and bathing, all contribute to degradation of source water quality. Unregulated private activity has a significant cumulative effect in Kisumu and fringe slum areas that border the Nyamasaria River.

**Picture 7. Truck washing in the Winam Gulf**

Car washing takes place wherever a vehicle has access. In towns with mechanic shops, it is also very likely that automotive fluids are tipped into gutters and open ground.

There is also active sand harvesting along the Kibos and Nyamasaria rivers, sometimes resulting into the shifting of the river course. River bank collapse is a serious problem adding to the sedimentation and turbidity problems.

# 6. ORONGO WATER POINTS

## 6.1. Location of Village Water Points

An attempt was made to identify all Orongo water sources, however detailed local maps were not available. The map in Figure 4 (Chapter 1.1) was drafted from elements of district maps, then incorporated village details from visual reference and knowledge of local residents.

The water sources in order of current usage for Orongo village are as follows: a) wells and boreholes, b) streams, c) rainwater, d) lake - Winam Gulf.

Wells are the major source of water in the village. Currently at least 16 sites exist, 3 drilled boreholes, 6 protected shallow wells, and at least 7 open, hand dug shallow wells. During the dry season the number of water points decrease, and some people are forced to seek substandard sources. Most of the 16 sites were visited personally and details recorded of their condition and the surrounding environment. Four wells and two boreholes were sampled for chemical and bacteriological quality.

The south-eastern part of the village, near the Luanda stream, gets more waterlogged, and hand dug wells collapse. There is a borehole, but a 10 minute walk (500 m) from Nyaimbo Primary school. 300 students depend on a visibly polluted stream for drinking water.

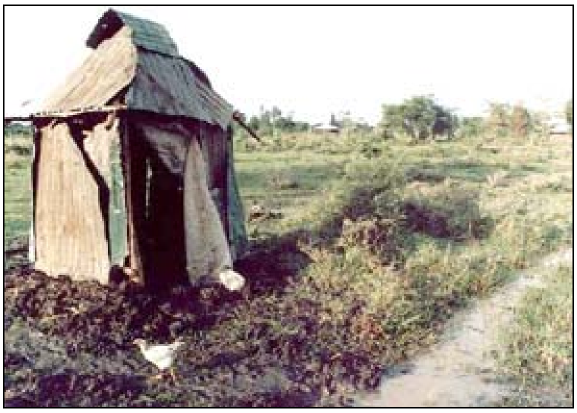
Most of the village population is concentrated in three areas, Orongo, Nyaimbo, and Buoye. Each has a school, and two or three nearby churches. As the region has receives moderate precipitation, rainwater should be a valuable source. However, storage tanks were not present on any of the communal buildings, and only a couple families had them.

## 6.2. Surface Water Source Hazards

### 6.2.1. Poor Sanitation

One gram of faeces is said to contain 10,000,000 viruses, 1,000,000 bacteria, 1,000 parasite cysts, and 100 parasite eggs. The most obvious source of contamination of village surface water is from poor sanitation.

Orongo is largely dependent upon hand-dug pit latrines, with about 60% of villagers having them (Ombwayo, 2004). These are usually not greater than 1.5 m in depth and subject to frequent collapse when the ground becomes waterlogged. In the absence of latrines, it is common for people to defecate in the bushes, contributing to pollution of water sources. Sub-surface water movement is rapid at times, and poor sanitation is likely the most significant factor towards microbial contamination of well and surface water.



**Picture 8. Typical pit latrine and standing water**

### 6.2.2. Turbid Flow and Pollutant Build-up

Great changes in flow conditions cause rapid variations in raw water quality and reliability. There is great variability within even a day of heavy rain, and certainly between wet and dry seasons. A higher retention time is good for sedimentation, but negative in terms of flushing out pollutants. The Orongo streams are of high risk at both low volume and higher flow.

Land use is not as intensive like that in the upper watershed, but the low-lying plain promotes direct loading of silt and contaminant. Some research has documented levels of copper residues in the River Ombeyi waters just a few km east of Orongo; this could be a residue from fungicides applied in irrigated rice schemes. (NEMA, 2003)

Although the least important drinking source for Orongo, Winam Gulf is one of the most serious pollution hot spots of Lake Victoria. Water quality is becoming critical due to anthropogenic pressures and limited Gulf water circulation that results in a retention time of nearly 20 years.

## 6.3. Groundwater Source Hazards

### 6.3.1. Aquifer Hydrogeology

It is useful to understand the groundwater infiltration rate, direction, dilution characteristics, and hydrogeology to assess the vulnerability and potential leaching of microbial contaminants into the aquifer. Boreholes in Orongo are about 70 m deep, but wells range from 20m to only about 6m. The hand dug shallow wells can reach the water table at 3 - 5 m.

Nyanza province is typified by basement aquifer with a high degree of variation in weathering and fracturing. The hydrogeology is complicated by the presence of volcanic intrusions in some areas. Aquifers in fissured limestone or volcanic rocks and underlying thin soils are very vulnerable to biological contamination from pathogenic organisms and other forms of waterborne pollution. Particularly when the aquifer is phreatic (without an upper confining layer) and at shallow levels, as is common in floodplain locations, water from unprotected wells will commonly have coliform levels in excess, often grossly, of WHO limits.

Unconfined conditions with a shallow water table and groundwater under direct influence of surface water, greatly increases the contamination risk. The Luanda stream was assessed to be supplying recharge to the ground water. (DHV, 1987) As shallow ground water in Orongo moves quite rapidly it is at very high risk for microbiological contamination. Wells could also potentially be at risk to agrochemical pollutants, depending on the level of reduction due to particle bonding and decomposition.

### 6.3.2. Topographical Features Facilitating Pollutant Transport

Due to the floodplain location, part of the village usually is under some water every rainy season; a significant hazard to any wells not completely sealed. The topsoil has high clay content so after rainfall water stands for long periods and increases the chance for stagnation and spread of pathogens.

The presence of features such as abandoned wells can be conduits that greatly increase the risk that pollutants get transported directly to the aquifer. There are at least two old wells that should be addressed, one near Orongo School, and the other at Nyaimbo School. The flow of shallow ground water follows the topography, which is from northeast to southwest, therefore should be considered when assessing significance of potential pollution sources. (DHV, 1987)

### 6.3.3. Well and Borehole Survey

Field investigation of Orongo drinking sources involved a detailed survey of the physical status of water points, and the immediate surrounding environmental conditions. See Appendix C for a summary description of wells, and boreholes, and surveyed conditions.

6.3.3.1. Location of Wells

The entire village area is rural, but quite densely populated with 20 – 30 homes in view at any one time from a water point. In a couple cases latrines are within 20-30 m from highly used, protected wells. There seems to be little control or guidance as to the digging of unprotected, hand dug wells. Some of these are located just a couple meters outside people’s front doors.

### 6.3.3.2. Well Protection

Most Orongo residents rely upon groundwater for their drinking supply. The three boreholes seem in good condition. Of the 13 shallow wells inspected, just 6 were protected with concrete casing, cover, and hand-pump. In general they are well designed; with hand pump, elevated protective concrete slab, good wellhead, spillway drainage, and two with a protective wall to keep animals away.

However, each of these 6 wells has a casing that is not completely sealed. There are two 5 cm diameter holes in every 1m ring, apparently used for hooks during installation. These holes have been left unsealed, allowing contaminated water to seep in. This is a very significant risk as flooding up to the water points often occurs to varying degrees.

Of further concern is the number of hand-dug unprotected wells, 5-6 m deep with no casing, and at best a mud and wood covering. 7 were spotted, but there are likely many more, with locations changing. The walls are mud, and there is no protection from animals, small children, or polluting material falling in. The sides often collapse, and on the first few occasions someone is lowered down to dredge out the earth. Usually within 6 months to one year it must be abandoned.

### 6.3.3.3. Water point Hygiene and Practices

There is high risk if there is inadequate fencing allowing in animals or washing activities taking place at the water point. Only two sites were seen to have a walled structure controlling access and keeping animals away. Rules regarding the use of the hand pump include no bathing, no washing of buckets or clothes at the water point. Some of the pumps are locked when not in use and the caretaker is expected to clean the apron after the end of every day.

**Picture 9. Broken Obuso well with open access**

An unlocked cover could allow contaminated objects to drop into the well. At least one well was being operated under extremely unsanitary conditions. While sampling water, one of the wells we came to test had a broken hand pump, so the trap door had been opened for access. Since the well was not fenced off from animals, the bucket and rope left on the ground was sitting in cow faeces. Without any consideration, it was lowered into the well. Inquiry confirmed that the water is used for drinking.

It was commented by an accompanying Government chemist that in his own village, the elders would visit households to educate and ensure safe practices were being followed (Achuma). Further research is required to better understand the average hygiene standards.

## 6.4. Water Quality

### 6.4.1. Water Quality Constituents

Quality of water is affected by the presence of various substances that can be generally classified under the following criteria:
a) Physical conditions such as temperature, sediments, and turbidity caused by suspended solids preventing light penetration.
b) Pathogens include causative microbiological agents of water-borne diseases such as typhoid, dysentery, and viral hepatitis.
c) pH and related constituents such as carbon dioxide, carbonate, bicarbonate, acidity and alkalinity.
d) Oxygen-consuming substances, consisting of organic compounds that are degraded by micro-organisms using oxygen dissolved in the water.
e) Toxic substances include a variety of hazardous materials that endanger human health.
f) Substances of special ecological concern such as heavy metals or persistent pesticides, which are not readily biodegradable and accumulate (bio-magnify) in the food chains.
g) Nutrients like phosphorus and nitrogen, which promote the growth of algae and aquatic plants.
h) Chemicals creating aesthetic problems such as phenol and sulphides, which have objectionable aesthetic properties.
i) Radioactive substances that have harmful effects on all organisms in the ecosystem.
(Thanh and Biswas, 1990) See Appendix B.1 for more detailed water quality descriptions.

### 6.4.2. Natural Hydrochemistry

The chemistry of natural surface water and groundwater is controlled by the composition of the source rainfall and by various chemical and physical processes. The chemical processes mostly relate to interactions between water and rock material. The physical processes include fluid mixing, which in the low-lying plain context, mainly refers to stream/river recharge. (Falkenmark, 1987)

During infiltration, the content of carbon dioxide increases in the soil because of its organic content and the chemical composition continues to change in accordance with chemical interactions with the host rock. These changes are accelerated with higher temperature and account for the increased rate of weathering of rock material in tropical regions. The breakdown of the main component minerals of basaltic and andesitic volcanic rocks, such as olivine, pyroxene, and plagioclase feldspar, releases magnesium bicarbonate and silica, which are dominant ions in associated groundwater. The total ion content of carbonate groundwater is generally higher than volcanic rock groundwater because of the ready solubility of limestone in weakly acidic circulating groundwater. The presence of other cations, notably magnesium, in the carbonate rock also increases solubility. (Falkenmark, 1987)

Groundwater is usually considered to have excellent natural microbiological quality and generally adequate chemical quality for most uses. Eight major ions and silica make up 99% of the solute content of natural groundwater. The cations: calcium, magnesium, sodium, and small amounts of potassium. And the anions: bicarbonate, sulphate, chloride, and small amounts of nitrate. The proportion of these constituents reflects the geology and history of the groundwater as it contacts various mineral deposits.

Minor and trace constituents make up the remaining 1% of the total, and their presence (or absence) can occasionally give rise to health problems or make them unacceptable for human or animal use (Edmunds and Smedley, 1996). Health problems are associated with elevated concentrations of arsenic and fluoride, or the deficiency of iodine. In some places the total salt content of the water is high and makes the water unsuitable for drinking.

Other less prevalent ions include the cations: ammonium, arsenic, boron, copper, iron, and manganese. And the anions: bisulphate, bisulphite, carbonate, fluoride, hydroxide, phosphate, sulphide, and sulphite. Most of these are also derived from mineral deposits. In addition, some ions such as ammonium carbonate and sulphide are produced by bacterial and algal activities. (Thanh and Biswas, 1990)

### 6.4.3. Priorities for Standards and Selection of Test Parameters

Legal enforceability is mainly what differentiates standards from guideline values. Water quality criteria, standards, and the related legislation are used as the main administrative means to manage water quality in order to achieve user requirements. The Kenya Bureau of Standards has in place formal specifications for drinking water that include aesthetic requirements, microbiological limits, and limits for inorganic contaminants, organic constituents of health significance, and radioactive materials.

The WHO states priorities for drinking water as:
- Access is key priority even where quality is inadequate.
- The priority water quality concern is microbiological because of the link to health and acute disease.

Priority microbes considered in the WHO GDWQ (2004 c):
1) Orally transmitted pathogens of high priority (microbes associated with human faeces).
2) Opportunistic and other water associated pathogens (moderate priority).
3) Toxins from cyanobacteria.

The parameters to test can be prioritized with consideration of the catchment pollution risks, knowledge of the typical local water conditions, geology, and soil that would predispose to certain elements. The most critical parameters relevant when testing rural Kenyan sources are:

**Table 5. Critical parameters and Kenyan standard** (KEBS, 1996)

| Parameter | Acceptable range |
|---|---|
| Faecal coliforms | 0 cfu. / 100 ml |
| Turbidity | < 5 NTU |
| Disinfectant residual | 0.2 - 0.5 mg/l |
| pH | 6.5 - 8.5 |
| Fluoride | 1.5 mg/l |

See Table 7, a summary of the well and borehole quality analysis results, for additional parameters of the Kenyan water standards and WHO Guidelines.

Pathogens and disease causing micro-organisms are the most important consideration for rural water points. The WHO states: "*The microbiological quality of drinking water is of the highest importance and must never be compromised. Ideally, drinking water should not contain any micro-organisms known to be pathogenic. It should be free of all bacteria indicative of pollution.*"

**Table 6. Risk related to faecal coliform (FC) contamination level**

| Number of FC per 100 ml | Health risk of consuming water |
|---|---|
| 0 | In compliance with WHO guidelines |
| 1 – 10 | Low risk |
| 10 – 100 | Intermediate risk |
| 100 – 1000 | High risk |
| > 1000 | Very high risk |

Source: SANDEC, 2002

However the risk related to different levels of contamination must be assessed considering the local circumstances. The risk related to a given contamination increases with the number of people being supplied by a water system. The WHO GDWQ (2004 d) classifies the presence of 1-10 FC per 100 ml in water supplies as low risk. See Table 6.

### 6.4.4. Water Quality Analysis Results

Water quality testing aims to generate information on the quality of the resources within the coverage area and to establish baseline information on the present conditions. Data on such analysis will serve as benchmarks for comparison with future monitoring activities. Ideally the number of samples taken and locations should aim to achieve a statistically unbiased survey, but this in reality is often limited by lack of resources.

During the field study, 2 boreholes and 4 protected shallow wells in Orongo were sampled. Other scattered reports did contain some data about the Winam Gulf, Nyando and Kibos Rivers, and a few parameters from rainwater tanks studied in the region.

For perspective, results of a Kisumu District State of the Environment (NEMA, 2003) source water survey can be considered. The lake water, all the 14 streams, all surface catchment pans, 82% of springs, 55% of shallow wells, and 12% of roof catchment, had water quality unacceptable for drinking. Boreholes and piped schemes were considered the safest sources in the district.

#### 6.4.4.1. Wells and Boreholes

According to residents, Orongo means “salty rock” in the local Dhuluo language. It is common in the region, especially closer to Lake Victoria, that deep boreholes have high level of salinity. The village primarily relies upon groundwater for drinking. The main quality concerns are: 1) microbiological contamination, 2) fluoride, 3) high mineral content.

Six groundwater sources were sampled. Shallow wells tested all were protected with concrete casing and had hand pumps, yet were found to contain FC contamination at levels indicating intermediate and high risk to health. Only the boreholes were considered low risk or able to meet the standards, likely due to their greater depth (70m) and sealed narrow casing.

Although the boreholes can be considered bacteriologically safe, the water is not always palatable. Especially Kanyawade contains a high mineral salt content, and perhaps sulphate or hydrogen sulphide as a slight egg smell was noticed. Sodium bicarbonate water is typical of the area, with low hardness yet high alkalinity. In the long term fluoride is the greater problem, affecting the development of children’s bones and teeth, especially if they do not receive fluids from other sources. (Jacks, 2004) Fluoride is definitely a concern, especially as the borehole values of 3 mg/l twice exceeded Kenya standards and WHO GV. See Table 7 below for the analysis results.

**Table 7. Groundwater quality analysis results and most significant values identified**

| **Parameter** | **Units** | **1. Florence** | **3. Kanyawade** | **4. Obuso** | **5. Kacholla** | **2. Kanyawade** | **6. Kacholla** | **WHO GV** | **Kenya Std** [4,6] |
|---|---|---|---|---|---|---|---|---|---|
| type of source (P=protected) | | P. well | P. well | P. well | P. well | borehole | borehole | | |
| **MICROBIOLOGICAL** | | | | | | | | | |
| Total Coliforms (37C) | cfu / 100 mL | tntc | 280 | tntc | tntc | 42 | 38 | | absent |
| E. coli / Faecal Coliforms (44C) | cfu / 100 mL | 14 | 40 | tntc | 188 | 2 | nil | | absent |
| **PHYSICAL** | | | | | | | | | |
| Colour | TCU | bit cloudy | clear | very cloudy | very clear | very clear | very clear | 15.0 | 15.0 |
| Conductivity | uS/cm | 2910 | 7180 | 3450 | 4920 | 5500 | 3180 | | |
| pH | | 7.53 | 7.26 | 7.36 | 7.54 | 7.35 | 7.24 | | 6,5 - 8,5 |
| Turbidity | NTU | 10 | nil | 35 | nil | nil | nil | 5 | 5 |
| Oxygen Absorbed (PV), 4hr at 27°C | mg/L | 0.5 | 0.3 | 0.3 | 0.2 | 0.4 | 0.3 | | |
| **CHEMICAL** | | | | | | | | | |
| Carbon Dioxide Free ($CO_2$) | mg/L | 5.0 | 10.0 | 10.0 | | 10.0 | 8.0 | | |
| Chloride ($Cl^-$) | mg/L | 18.0 | 15.0 | 20.0 | 25.0 | 75.0 | 50.0 | 250 | 250 |
| Fluoride ($F^-$) | mg/L | 2.0 | 2.0 | 2.0 | 0.8 | 3.0 | 3.0 | 1.5 | 1.5 |
| Iron (Fe) | mg/L | 0.1 | trace | nil | 0.2 | 0.3 | nil | 0.3 | 0.3 |
| Nitrite ($NO_2^-$) | mg/L | 0.0006 | | trace | nil | trace | trace | 0,2 chronic | |
| Nitrogen - Free Ammonia ($NH_3$ ) | mg/L | 0.08 | 0.04 | 0.04 | 0.20 | 0.04 | 0.04 | 1.5 | 0.5 |
| Phosphate ($PO_4^{3-}$) | mg/L | 0.175 | 0.175 | 0.319 | 0.071 | 0.505 | 0.059 | | |
| Alkalinity Phenolphthalein ($CO_3^{2-}$) | mg/L | nil | nil | nil | 5.0 | nil | nil | | |
| Total Alkalinity | ng CaCO3/L | 700 | 840 | 840 | 950 | 800 | 600 | | |
| Total Dissolved Solids(Calc) | mg/L | 1940 | 4786 | 2300 | 3280 | 3666 | 2120 | 1000 | 1500 |
| Total Hardness | mg CaCO3/L | 30 | 20 | 20 | 23 | 38 | 30 | | 500 |
| Non-Carbonate Hardness | mg CaCO3/L | 0 | | | 0 | 0 | 0 | | |

Sources: Kenya Bureau of Standards (1996), UNEP Kenya Country Water Report (2004 a), WHO (2004 c) Sampling Date: 18/12/2003

Electrical conductivity (EC) is a good measure of relative mineral concentration. The 6 wells tested had values ranging from 2910-7810 µS/cm, indicating that the dissolved organic salts are extremely high, and a poor source for drinking. Alkalinity likely contributes to the high EC, along with evaporation of shallow ground water. (DHV, 1987) According to Bergelin et al (2002), normal Swedish groundwater has about 40 µS/cm, while seawater has several thousand µS/cm. Water with EC values above 2000 µS/cm may not be suitable for use.

Total dissolved solids (TDS) can be estimated from the conductivity times 0.7. The TDS is high for all samples, some tripling standards. High salinity reconfirms that the water is not satisfactory for people, and crops would be very adversely affected. Pumps could also be in concern, as TDS above 3000 mg/l can corrode pipes in a year. (Thanh and Biswas, 1990)

### 6.4.4.2. Rivers and Streams

From observation, it is apparent that there is a significant sediment load to Luanda River. The banks are completely void of protective vegetation in most places, due to close cultivation, open grazing, watering of livestock, and domestic washing. It is seasonal, usually dry in January and February. The Luanda was observed to be approximately 10m wide, shallow, silted, and of little flow. In places the bed level was hardly below average ground level.

Visually, the colour was a dark chocolate brown, with extreme turbidity. An estimate of Luanda quality can be based on the Nyando River, within 20km and with similar upstream conditions, and the Kibos River, which feeds into Luanda stream. Nyando is reported to have the highest nutrient discharge in the entire Lake basin. The Kibos has a very high silt load and nutrient levels. (NEMA, 2003) No microbiological data on the watercourses was obtained, but they are obviously grossly contaminated. Surface runoff from grazing cattle and unlined pit latrines would probably classify the Luanda stream with a quality near to sewage water.

**Picture 10. Turbid Luanda stream near Nyaimbo**

**Picture 11. Luanda is nearly transparent after passing through dense papyrus**

It is important to point out the obvious potential for self-cleaning of surface water with filtration through thick papyrus and hyacinth vegetation. Luanda stream is extremely turbid and murky brown behind Nyaimbo School, yet the water reaching the Gulf is nearly transparent. This is likely the best quality, untreated surface water available in the village. Unfortunately it is more than a 2 km walk from most residents.

### 6.4.4.3. Rainwater

Rainwater harvesting (RWH) has come to mean the utilisation of rainwater close to the point rain reaches the earth. Rooftop RWH is a simple technology, but with few exceptions, is inherently a small-scale approach. In its simplest form, it consists of using the flat or sloping roof of a residence or other structure and then gutters at the edge of the roof directing the water toward a storage tank. Thatched roofs can be used to collect water but they are both less effective and more subject to contamination than metal or other solid roofs. Elevated levels of organic matter have been noted (Downes, 1981) in water collected from roofs made of traditional thatch materials. Lead-based paints or asbestos panels are a more serious concern.

Achuma (2000) investigated the conditions of various storage tanks, collection surfaces, level of maintenance, and quality of stored rainwater. A study of 20 roof catchment tanks located at schools in Western and Nyanza provinces shown an overall acceptable quality of water, especially considering no treatment and or diversion mechanism. 4 tanks tested positive for faecal coliforms, but only one was extreme with 60 colony forming units (cfu), the other 3 had just 2 cfu. This contamination can be traced to birds or bat droppings on the roofs that didn't get diverted. Iron content was high in two of the tanks, linked to rusty roofs. Although the WHO has no enforceable health standard for iron, values above 0.3 mg/l are considered excessive aesthetically; staining cloths and other items. One tank exceeded with 0.409 mg/l, and 4 were near 0.3 mg/l. The rather high turbidity levels, although not a direct health concern, could slightly hinder chemical disinfection efforts. Turbidity is attributed to lack of first flush diversion and insufficient cleaning of the tanks. (Achuma, 2000)

Rainwater may not even be entirely fluoride free, as it may pick up some from atmospheric aerosols as it falls. A study by Moturi et al (2001) in Nakuru 100 km from Kisumu, found some low amounts ranging from 0.5–0.9 mg/l. Other anthropogenic influences on rainwater are $NO_x$ emissions from vehicles, and particulates linked to burning of wood and coal, but these have not been identified as a health concern so long as the first minutes of rain is diverted. Some variations in the chemical composition of rainfall occur, both seasonally and in single storm events during which dilution increases with time.

6.4.4.4. Winam Gulf

The Winam Gulf is under significant anthropogenic pressure from agricultural runoff, animal, and human waste. The problem is compounded since it is a semi-isolated “finger” that has limited circulation with Lake Victoria. Some water quality data was found in LVEMP and KMFRI monitoring reports.

Though variation of pH was reported to be low, high alkalinity was recorded in the waters around Kisumu bay. Turbidity levels were highest in the inshore waters around Kisumu Bay and at the mouth of River Sondu Miriu ranging from 30 – 45 NTU, decreasing with the distance into the inner waters. Inshore waters of the Gulf also reported high conductivity figures as an indication of the presence of ion radicals. According to the State of Environment report (2003) the source of the nutrients is mainly the agricultural runoff and discharges of domestic effluents from the settlements including Kisumu town. Another source of nutrients is mainly from rainfall, remineralisation and the nitrogen fixing cyanobacteria. High silicate levels around the inshore areas are mainly from terrestrial sources through surface runoffs.

# 7. HOUSEHOLD USAGE

## 7.1. Water Source Preferences

In selecting a source, the user typically considers water quality, technical feasibility, social relationships in getting the water, and economic efficiency. Costs are interpreted in terms of distance walked, time spent waiting in a queue or cash payments. Quality decisions are more likely based on taste, temperature, odour, and appearance than considerations of bacteriological quality, but still real. (Falkenmark, 1980)

Groundwater is used for most domestic purposes in the village. The sources most preferred are the boreholes and Kacholla protected well. Most of the 6 protected shallow wells are visibly very clear, and some users consider them safe and prefer them for being slightly less salty than the boreholes.

The most improved water points are controlled by attendants and usually collect a small fee. The locality of the boreholes is such that there are other alternative sources nearby such as hand-dug wells. From the site inspection, it was learnt that there are at least 7 hand-dug wells that are unlined, 3-5 m deep holes in the ground. These traditional water sources are mainly used for domestic washing and watering animals, but also for drinking by those unable to pay or too distant from the improved water points.

During the driest periods some of the shallow protected wells may become over-pumped, and unavailable except for early morning or late at night. According to the villagers interviewed, during the rainy season some of the shallow wells become discoloured and milky, and people with iron sheet roofing try catch some rainwater for their domestic needs with what ever small containers they might have available. The boreholes are reliable sources year round.

The seasonal streams in the area are used for washing, bathing, and watering livestock. The exception is the Nyaimbo School area in the southeast of Orongo, where shallow wells collapse, and the only borehole is 500 m from the school. Many school children and possibly some households resort to the visibly polluted Luanda stream (Picture 10) as a source of drinking water.

Picture 12. Nyaimbo school children

Picture 13. Lone homestead at Orongo beach

Orongo village, although having shores to the Winam Gulf, relies on the Lake waters only minimally, even during dry spells. The distance of 2 ½ - 3 km makes walking with large volumes impractical. The quality for drinking purposes is known to be unsafe, and villagers only resort to the Lake under extreme conditions with all their wells drying up. However one family does remain living and farming beside its shores, and the Lake is their primary source.

## 7.2. Water Collection Methods

Mostly women and children are responsible for the provision of water, although it was not unusual to see men collecting. It can take up to 15-20 minutes each way to collect water from a water point. Around central Orongo, with more source options, people seemed to walk 200m. But elsewhere, distances of 400-600 m are common to reach preferred sources. During times of drought, villagers are forced to venture further for water to a less suitable source.

The most common containers are plastic, 10–25 L jerri-cans, usually carried by hand or on the head. A typical household used an average of 3-5 twenty litre jerri-cans per day, meaning fetching chores of a minimum 1.5 hrs hours a day. Bicycles were sometimes observed being used for assistance, but not animals nor wheelbarrows. There is not usually scheduled times for collection, but if a well level drops, then water might only be available during early morning or late evening. Pictures 14 and 15 below give an idea of typical water points.

Picture 14. Collection at Florence's protected well

Picture 15. Some skilled carrying…

## 7.3. Handling and Storage Hazards

General water handling practices were understood from observation during household visits and informal interviews. Once carried into the home, drinking water is transferred to clay pots, often placed on the floor, with access through a wide top opening.

**Picture 16. A 20L jerri-can, modified clay pot, traditional clay pot**

**Picture 17. Traditional pot, dipping cup, sitting on floor of the home**

Clay is preferred for storage as it is considered to keep the water cooler and improve the taste. According to a survey by CARE Kenya (2003), 99% of households stored their drinking water in traditional clay pots.

Families usually have a communal cup to draw water from the pot and a cloth covering the opening. Water for other uses is kept in buckets or the plastic carrying containers. The design of the reservoir, its protection, and maintenance affect the potential for cross-contamination and microbial growth. A modified version of the clay pot, with a tap (spigot) and narrow cover, is locally available. It is not known how well adopted they are in Orongo.

There is research by Trevett (2002) that investigated the potential for water quality to deteriorate between the points of collection and consumption in rural Honduran communities. The water supply came from protected hand-dug wells and boreholes, all fitted with hand-pumps. They collected water in buckets and jerri-cans, and then transferred to a storage container usually made of fired clay and characterized by a wide neck, just as in Orongo. Source water samples from the boreholes had a mean of 1 FC /100 ml, and wells 111 FC / 100 ml; comparable quality to Orongo sources. However, analysis of the household storage containers discovered the well water became twice as contaminated, and the relatively safe borehole water became contaminated to an average of 72 FC/100 ml.

Furthermore, Trevett (2002) assessed the contamination in relation to serving method.

**Table 8. Mean FC / 100ml in stored drinking water compared by serving method**

| Serving method | Mean FC / 100 ml (number of samples) |
|---|---|
| Dip (cup or beaker) | 86 (74) |
| Ladle | 182 (77) |
| Pour | 23 (78) |

Source: Trevett, 2002 (data is from borehole sources)

The contamination during collection was identified and explained as follows:
- Dirty hands or collection containers would cause the initial deterioration in water quality.
- Collection containers not covered during the journey home could be exposed to any airborne contaminants. Probably more import is hand–water contact as it is being lifted and when steadying the container while walking.
- In Trevett's study, no statistically significant difference in stored water quality resulted from covering the container compared to not covering.
- A test on female householders found that faecal contamination was present on 44 % of fingertips tested during normal household activities; easily transferred to water. Furthermore, faecal material was also detected on cups and beakers used for serving stored drinking water.
- The hands of young children may be expected to be more contaminated with faecal material than an adult's, so children serving themselves would introduce contamination.
- Straining the water through an unclean cloth will introduce contamination.
- A comparison of different serving methods revealed that poured water exhibited much less contamination than in those using a ladle or cup to dip into the container.

This study has very relevant for Orongo, and residents would most certainly benefit from recognizing the above hazards and improving handling practices.

## 7.4. Current Treatment Methods

Inappropriate or insufficient treatment, poor reliability, or lack of a backup method, puts the residents at great risk of especially microbial contamination. Both boiling and chlorination methods are known in Orongo, but appear to be inconsistently practiced. Community members are also known to treat their water by settlement, storage, and simple cloth filtration. Boiling water is often neglected due to reliance on wood fuel, time pressure, and the effort involved in collecting wood. No other methods of water treatment were observed.

The Centre for Disease Control, CARE, and local organisations are promoting chlorination and safe water hygiene, and benefits seem to be known to at least some residents. The Orongo Widow's and Orphan's Group also helps in distributing chlorine solution and advice to needy families. However, widespread adoption may be inhibited due to a) decisions based on cost b) belief that their source well water is fine (since it looks clean) and no need of a new practice c) unfavourable taste of treated water d) belief that chlorine may be a contraceptive or unhealthy in some way. A very practical guide called "A Manual of the Safe Water System" is available so that heads of households can easily understand and adopt safer practices. (CARE Kenya, 2003)

## 7.5. Pricing and Ability to Pay

A major economic concern for residents will be the cost for their water supply and what can be afforded. In Orongo, the improved water points, boreholes and protected wells, were constructed through both development project and village church funding. The community is expected to meet all on-going maintenance and repair costs, therefore charging a levy of 0.50 KES per 20 litres. Although because of irregular income patterns and availability of alternative water sources many members of the community were not willing to pay for water from protected water sources.

## 7.6. Consumption and Future Demand

According to the Central Bureau of Statistics, in 2001 Nyanza average household sizes were 4.5 people. From observations, Orongo is estimated at about 6 / HH. In terms of volume considerations, this study focuses on the most essential needs for drinking and cooking.

It should be pointed out that the terms consumption and demand are *not* interchangeable. Consumption means the actual volume of water gathered. Demand will vary according to access, quality and education of a population; people might use more water had they the opportunity. Demand can outstrip supply, consumption cannot. Water use, consumption, and extraction are measurable factors, with in theory a real value. Need and demand are subjective values requiring a qualitative determination. (Clark et al, 2001)

### 7.6.1. Water Use and Volume Consumed

The amount of water consumed depends on whether it has to be carried to the house, the number of people in the household (the larger the household the smaller per capita use), and the amount of washing done at home. The average person in the developing world uses 10 litres of water a day; about 5 L of this is for cooking and drinking. The World Bank estimates that a further 25-45 L would be needed for each person to stay clean and healthy. If she carries only enough water for her family (husband, mother, five children) to survive each day, she would need to fetch about 40 L. But to keep them all clean and healthy she would need to fetch 200 L of water every day. (Rehydration Project, 2004) Women in a typical Orongo household collected an average of 3-5 twenty litre jerri-cans per day.

An estimate of "essential" community consumption is obtained by taking total population with the average usage of 5 L per person. For the purpose of latter calculations, it is assumed that an adult drinks about 3.5 L per day, and 1.5 L is used for cooking. The village's (of 3000) essential consumption is therefore about 15,000 L per day.

### 7.6.2. Assessment of Future Demand

Planning and management of water resources requires an idea of what future needs are expected to be. The primary inciting factor will be related to changes in population. Household demand can be extrapolated from current consumption rates, with consideration for changes in technology or usage pattern. It is also known from research that proximity to the source affects consumption, so that additional water points might increase per capita use. Agriculture, livestock, and water consuming new businesses are outside of the scope of this study, but might make up a significant part of the total demand.

At present, the volume of water available can become a problem during abnormally dry seasons. With a growing population, additional water sources will be needed in Orongo. If the annual growth rate is simply assumed 2.5%, the population in 15 years will be increased by a factor of $(1.025)^{15} = 1.448$, or by about 45%. Therefore we could estimate there to be 4350 people in the village by 2018. Without any allowance for increase in per person consumption, the village will consume 4350x 5 L = 21.75 $m^3$ for drinking and cooking on an average day.

# 8. HAZARDS AND RISK ASSESSMENT

The systems approach to identification of contamination sources is illustrated in Figure 10. It includes an assessment of all types of physical, chemical, and microbiological risks to drinking water, from upstream in the catchment, the village water sources, during handling, storage, and treatment in the home.

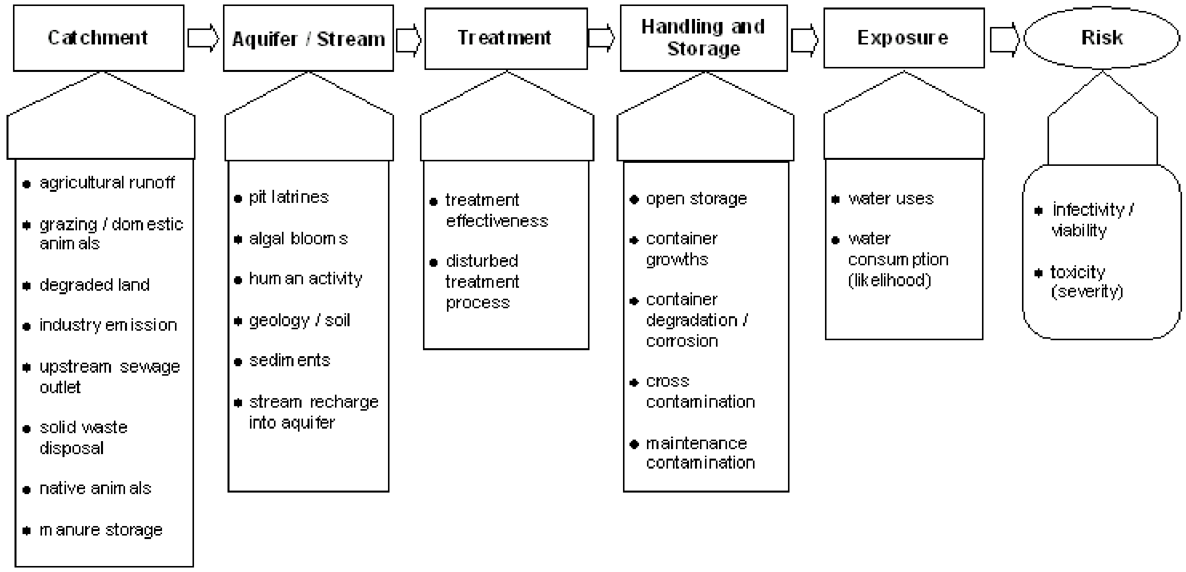


**Figure 10. Flow diagram for sources of contamination risk to drinking water**

Hazards and risk factors are assessed qualitatively as according to the definitions in Table 10, based on estimated likelihood of possible risk pathways, severity of outcome from each pathway, and number of people that may be impacted. (OECD, 2003)

**Table 9. Simple scoring matrix for ranking risks**

| | Severity of Consequences | | | | |
|---|---|---|---|---|---|
| **Likelihood** | **Insignificant** | **Minor** | **Moderate** | **Major** | **Catastrophic** |
| Almost certain | ▒ | ▦ | ▓ | ▥ | ■ |
| Likely | ░ | ▒ | ▦ | ▓ | ▥ |
| Moderately likely | | ▒ | ▦ | ▦ | ▓ |
| Unlikely | | ░ | ▒ | ▒ | ▦ |
| Rare | | | | ░ | ▒ |

**Table 10. Definitions of risk scoring Likelihood and Severity categories**

| Likelihood of Occurance | | Severity of Consequences | |
|---|---|---|---|
| Almost certain | Once per day | Catastropic | Potentially lethal to a large population |
| Likely | Once per week | Major | Potentially lethal to a small population |
| Moderately likely | Once / month | Moderate | Potentially harmful to a large population |
| Unlikely | Once per year | Minor | Potentially harmful to a small population |
| Rare | Every five years | Insignificant | No impact or not detectable |

Source, adapted from WHO, 2004 a

The identified contamination risk factors from catchment, village water points, and household, are summarized in Table 11. Application of the scoring relies upon knowledge gained from field study and literature review, with subjective judgements made on the health risks posed by hazards or hazardous events. The outcome of the hazard and risk assessment is a priority list for risk management to determine areas requiring immediate attention.

**Table 11. Qualitative risk assessment and hazard priority list**

| Hazards | Risk Assessment | Priority |
|---|---|---|
| • geology (naturally occuring chemicals) - high fluoride levels | ▒ | 4 |
| • climatic and seasonal variations, natural disasters - flooding and cholera epidemic | ▦ | 3 |
| • land use changes - population pressure, intense development | ▒ | 4 |
| • rapid variations in raw water quality - intense rainfall events | ▦ | 3 |
| • agriculture - agrochemical use in catchment | ░ | 5 |
| • inadequate buffer zones on watercourses; soil erosion and failure of sediment traps | ▓ | 2 |
| • human access - car washing, automotive chemicals, sand harvesting |  | 6 |
| • pit latrines discharge - poor sanitation | ▥ | 1 |
| • unconfined and shallow aquifer - rapid groundwater flow and recharge from streams | ▓ | 2 |
| • topographical features - low, flat areas accumulating water; abandoned wells | ▒ | 4 |
| • inadequate well protection - unsealed casing or no protection at all | ▥ | 1 |
| • unhygenic practices - at wells, during handling and storage | ▓ | 2 |
| • inadequate treatment methods - insufficient or inconsistant | ▥ | 1 |

The most urgent hazards and risks facing Orongo are pit latrine discharge, inadequate well protection, and inadequate treatment methods. Next most important are hygiene practices, and inadequate buffer zones (at least within the village). Aquifer hydrogeology and awareness of groundwater flow will aid in establishing better safety zones from pollution sources. Specific control measures are recommended in the conclusion, Chapter 11.

# 9. RECOMMENDED DRINKING WATER IMPROVEMENTS

A multi-method approach is required to provide different parts of Orongo village with a safe drinking supply throughout the year. Depending on the source, a combination of methods may be required to provide potable water. The “appropriateness” of methods implies conditions of affordability, ease of construction, maintenance, repair with locally available materials and competence, and replicable to other similar areas.

## 9.1. Utilize a Safer Supply

### 9.1.1. Expand Rooftop Rainwater Harvesting

Given the significant rainfall received during the wet seasons, it was quite surprising to see little utilization of this potentially high quality resource. From observation, more than 50% of homes in Orongo have steel roofing. The community buildings alone (8 churches, 3 school areas, and central market place) have significant roof area with the potential to supply the village essential drinking water for most of the year, if not the entire year. 16 RWH tanks ranging from 10-55 $m^3$, can provide at least 3000 people, 3.5 L per person per day based upon average rainfall patterns. See Appendix D.1.2 for supply and sizing calculations.

The general concept of rain harvesting is simple; however designs should be adapted for local conditions. Construction and maintenance techniques are fully within the capabilities of local people, and in most cases, they can use local materials. Community-level training is recommended to ensure rooftop systems are used efficiently and that storage is safely provided. SANA operates out of Kisumu and has experience building over 100 systems.

**Picture 18. Ferro cement RWH tank built by SANA**

The choice of design will depend on a number of technical and economic considerations:

- · Space availability
- · Local traditions for water storage
- · Cost –new tank materials and labour
- · Ground conditions
- · Options available locally
- · Materials and skills available locally
- · Style of RWH – whether the system will provide total or partial water supply

9.1.1.1. Considerations to Maintain Quality

Generally the chemical quality of rainwater will fall within the WHO guidelines and rarely presents problems. Proper design and maintenance can keep a good bacteriological quality. In most cases, even if the stored water does not meet standards, it likely is better than the alternatives readily available. (Brooks et al, 2001)

These are some considerations to best ensure quality and health aspects of RWH:

- It is advised that the catchment surface always be kept clean to prevent bird faeces entering.
- Rainwater tanks should be designed to protect the water from contamination by leaves, dust, insects, vermin, and other industrial or agricultural pollutants.
- Rust from metal roofs can be also minimised with a “first flush” diversion mechanism.
- Tanks should be sited away from trees, with good fitting lids and kept in good condition.
- Incoming water should be filtered or screened, or allowed to settle to take out foreign matter. Divert the dirty ‘first flush’ water away from the storage tank. Water that is relatively clean on entry to the tank, will usually improve in quality; bacteria die off, if allowed to sit.
- Keeping a tank dark and in a shady spot will help prevent algae growth and keep it cool.
- Mosquito screens should be fitted to all openings to prevent breeding and spread of malaria.
- The area surrounding a RWH should be kept in good sanitary condition, fenced off to prevent animals fouling the area or children playing around the tank. Any pools of water gathering around the tank should be drained and filled. (ITDG, 2004)

- Cleaning the RWH system should be done when the tanks become nearly empty. Ideally this would occur before the beginning of the heavy rains in February-March.

Vital is the knowledge about safe water handling; requiring householder education in maintaining the quality of the collected water. From a project implementation point of view, water testing and monitoring is an important complement to rooftop water harvesting.

9.1.1.2. Cost of a RWH System

The main barrier to greater use of rooftop catchment is cost, and the most expensive part of a system is the storage tank. Ferro-cement is generally the best in terms of durability and ease to keep clean. Brick in the walls can substitute concrete to reduce cost. Typical systems for a household (5 $m^3$), cost on the order of 16,000 KES (US$200), which is more than most absolutely poor people can afford, or even amortize from the sale of crops or animals. Alternative forms of payment are often needed, with the justification based on social benefits. (Brooks et al, 2001)

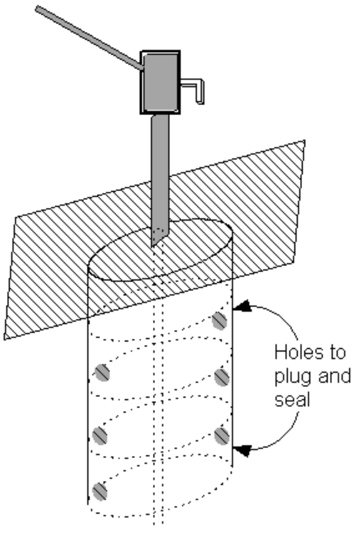
SANA is building RWH tanks in the Kisumu region, 4.6 – 23 $m^3$ for homesteads, and 45 $m^3$ for schools. The cost of a 45 $m^3$ Ferro cement tank system, including roof gutters, piping, transport and labour cost totals 126,000 KES. (SANA, 2003) As calculated in Figure D.4, Appendix D.1.2, this tank could cumulatively supply about 325 $m^3$ of water annually. Assuming a 5 year payback period, it means about 78 KES / $m^3$ or 1.56 KES / 20 L.

The social cost effectiveness aspects are also important to recognize. Lower levels of water-borne disease, reduced work time for women, and improved nutrition are all non-monetary benefits that ideally should have an aim to be quantified. The benefits of rooftop water harvesting typically have a strong gender component, so women should be involved more directly in all aspects of the projects. Unless the water is drawn off for irrigation, women will typically be more interested in the opportunities than men. (Brooks et al, 2001)

### 9.1.2. Repair Existing Shallow Wells

It appears the protected shallow wells may be contaminated because they were not properly constructed. Sealing, cleaning, and disinfecting the wells may restore safe water. With each casing ring, the holes in the sides should be plugged!

An internal inspection of the casing should be carried out and holes and cracks repaired where necessary. It should be part of the regular annual maintenance that the wells are pumped out and someone sent down to clean the inner sides of the well and remove any organic material or contaminating objects from the bottom. This requires a pump that is faster than the rate of refilling. After this repair and cleaning, shock disinfection is necessary before use. Florence's well has a cracked casing that needs to be fixed. The Obuso well needs the hand pump repaired or replaced. At the very minimum, the immediate area should be fenced from animals and the rope and bucket should be kept clean and always hung up, off the ground!



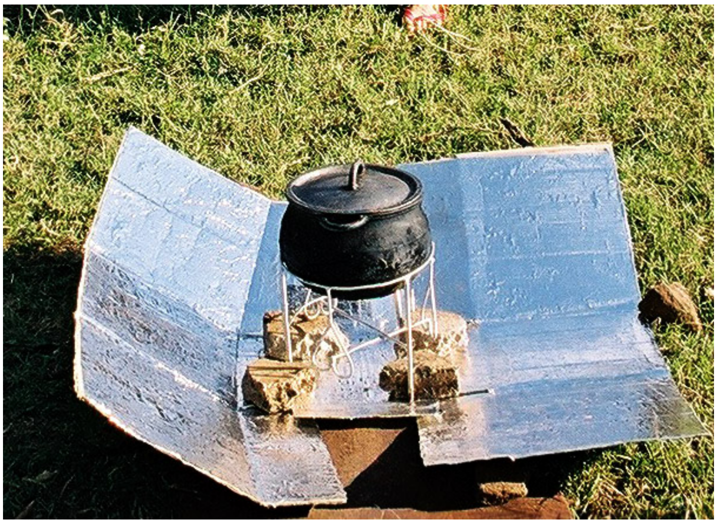
## 9.2. Low Cost Household Treatment Methods

Treatment systems of some sort will be required to ensure safe drinking supplies. Information on the contamination level of source water is the basis for the design of a treatment system. Designing an adequate system also requires knowledge of the efficiency of the processes in eliminating contaminants, and the drinking water quality standards that aim to be achieved. Several methods are available but there is a need to choose low tech and cost effective methods that villagers can afford to build, manage, and maintain.

### 9.2.1. Solar Pasteurization

Solar pasteurization means using the suns energy to heat water to a temperature sufficient to destroy pathogens. Boiling is likely to be well in excess of the heating conditions needed to dramatically reduce most waterborne pathogens. Pasteurization temperatures (60-65 °C) for periods of minutes to tens of minutes will destroy most waterborne pathogens of concern. (Sobsey, 2002) The system involves a dark, heat absorbing pot being placed in the focal point of reflective panels. Even the simplest construction can be effective, so long as the surfaces are shiny enough. Temperature monitoring can be done with a thermometer or visual indicator system such as a melting wax.

Solar reflector (solar cooker) methods of pasteurization are being promoted in the Lake Victoria region, and have been tested as effective. This was experimented with personally during field study. With a reflective surface of about 1m$^2$, and a full 5 L black iron pot raised on some stones, water reached a temperature hot enough to steam and melt candle wax within 2 hours under a midday sun. Angle adjustments were made every 30 minutes to maintain a focus on the pot.


**Picture 19. Solar reflector**

Materials required:
- cardboard (approximately 1.5 m$^2$; can be in sections)
- aluminium foil – to cover cardboard
- adhesive – ordinary office or paper glue works
- temperature indicator - thermometer, wax, or WAPI[5] (see below)
- iron or aluminium pot (3-10 L), blackened on outside with charcoal or paint

Cost:
Initial Set-up 100 – 200 KES (assuming household has a suitable pot already)
Operating at almost zero cost, but assumes annual small repairs of 100 KES.

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[5] A water pasteurization indicator (WAPI) is based on the melting temperature of wax. The WAPI is a clear plastic tube partially filled with a soybean wax and a piece of nylon line attached on each end to stainless steel washers. When the wax reaches 70°C, it melts and falls to the bottom of the tube, thereby giving a simple visual indication of when pasteurization conditions have been achieved. (Sobsey, 2002)

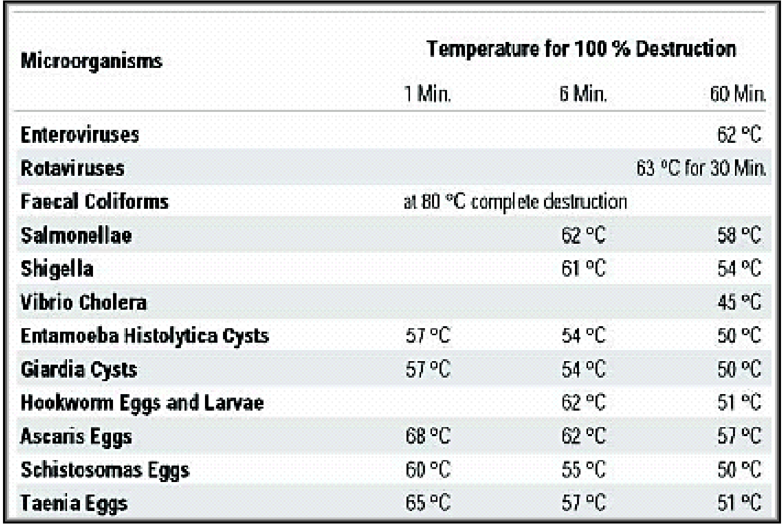
Efficiency:
If a dark container is highly exposed to solar radiation, the water temperature can reach 65°C, a pasteurization temperature capable of inactivating nearly all enteric pathogens within several tens of minutes to hours. See Table 12 below.

The WHO reported that a solar cooker system gives virus inactivation of 99.99% in 1.5 hours in a 1.4-L black bottle and 99% inactivation in 3 hours in a 3.8-L black bottle. Virus inactivation is only 90% in 3 hours using a simple 2-sided solar reflector and <30% using no solar reflector. (Sobsey, 2002)

Pasteurization requires 72°C for 15 sec. But even heating to as little as 55°C for several hours has been shown to dramatically reduce non-spore forming bacterial pathogens as well as many viruses and parasites, including protozoans Cryptosporidium, Giardia and Entamoeba. (Sobsey, 2002)

It is important to have an indicator device to be certain that sufficient temperature is reached.

**Table 12: Thermo-destruction of micro-organisms**



| Microorganisms | Temperature for 100 % Destruction | | |
|---|---|---|---|
| | 1 Min. | 6 Min. | 60 Min. |
| Enteroviruses | | | 62 °C |
| Rotaviruses | | | 63 °C for 30 Min. |
| Faecal Coliforms | at 80 °C complete destruction | | |
| Salmonellae | | 62 °C | 58 °C |
| Shigella | | 61 °C | 54 °C |
| Vibrio Cholera | | | 45 °C |
| Entamoeba Histolytica Cysts | 57 °C | 54 °C | 50 °C |
| Giardia Cysts | 57 °C | 54 °C | 50 °C |
| Hookworm Eggs and Larvae | | 62 °C | 51 °C |
| Ascaris Eggs | 68 °C | 62 °C | 57 °C |
| Schistosomas Eggs | 60 °C | 55 °C | 50 °C |
| Taenia Eggs | 65 °C | 57 °C | 51 °C |

Source: (SANDEC, 2002).

Advantages of solar cooker pasteurization:
- can be assembled from simple and low cost materials.
- microbial inactivation, including viruses
- less affected by turbidity or UV-absorbing solutes
- water can reach effective temperatures relatively quickly with a good reflective surface and peak sun conditions.
- additional uses that save on firewood and charcoal: water for tea and washing, heating of milk, and even cooking vegetables and eggs with peak conditions.

Limitations:
- only relatively small volumes (10 L) of water can be exposed conveniently at one time per water container and solar reflector.
- system requires solar collector or reflective panels to deliver sufficient solar energy
- poor effectiveness on cloudy days; availability of sunlight varies greatly with season, daily meteorological conditions and geographic location.
- potentially difficult to determine water temperature. Thermometers are relatively expensive. Waxes melt at different temperatures. The “WAPI” device is simple, reliable, and reusable.

### 9.2.2. SODIS

SODIS – Solar disinfection of water is being promoted in rural communities in countries such as Kenya to provide safe, household drinking water. The purpose of SODIS is the inactivation of pathogenic, diarrhoea causing micro-organisms. This photo-oxidative disinfection technique can effectively inactivate most pathogens from a variety of water sources, and is acceptable for rural communities in terms of ease of use, low cost and availability.

According to the WHO (Sobsey, 2002) the results of both microbiological and epidemiological studies indicate that solar disinfection of household water has the ability to appreciably improve its microbial quality and to reduce household diarrhoeal disease of consumers. It is an alternative water treatment option for use at the household level to disinfect small quantities of low turbidity water.

**Picture 20. SODIS** (SANDEC, 2002)

Materials needed:

- PET plastic (water or soda) bottles of 1 - 2 litre size, width less than 10cm. Clean, clear, transparent bottles without scratches and with tight fitting lids are important. PET plastic has less additives than the bluish PVC; cheaper, more effective, and more durable than glass. Estimate 2 bottles x 2L or 4 x 1L for each person; half in the sun and half ready to drink.
- resting surface – a small piece of corrugated galvanized iron (CGI) sheet works well since bottles placed on this has greater surface area in contact with hot metal. Both reflective and dark surfaces work. If house roof is iron or tin, can place bottles directly on a corner of it.
- Black paint – optional. Bottles can be painted black on one side and the CGI surface, to help increase temperature of water, especially in warm climates. In high altitude regions, where the water temperature remains cold, fully transparent bottles should be used in order to optimize the effect of UV-A. (SANDEC, 2002)

Cost:

- Initial setup 360* to 600 KES – Bottles and perhaps corrugated iron section. Assume a household of 6 persons, each with 4 x 1L bottles at a price of 15 KES per bottle.
- Annual operating cost is 360 KES*, assuming bottles need to be replaced once per year.

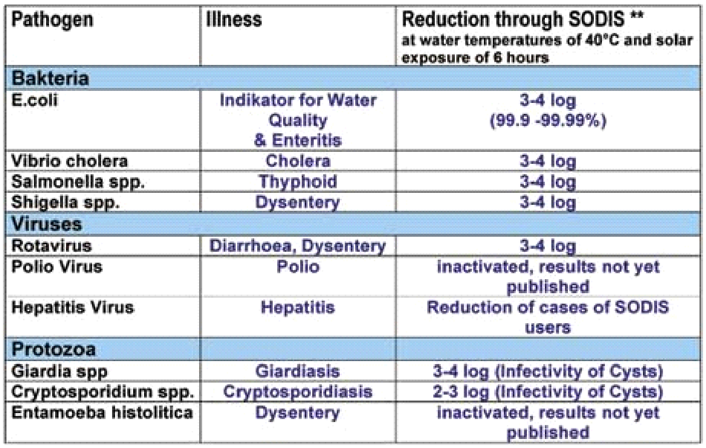
* negligible bottle cost if used ones are readily available.

Efficiency:

Research indicates that pathogenic bacteria and viruses are effectively destroyed by SODIS.

The method has been found to achieve a 3-log reduction of FC after at 5 hours of treatment at 30°C and sun of 500 W/m2. Table 13 indicates a 3-4 log reduction of many pathogens at 40°C and 6 hours exposure. If a water temperature of at least 50°C is reached, an exposure time of 1 hour is sufficient to kill 99.9% of the micro-organisms. (SANDEC, 2002) A 99.9% reduction means a very polluted well (100 - 1,000 cfu / 100ml) could be reduced to 0 – 1 faecal coliforms after treatment.

**Table 13. SODIS effectiveness at pathogen reduction**



| Pathogen | Illness | Reduction through SODIS ** at water temperatures of 40°C and solar exposure of 6 hours |
|---|---|---|
| **Bakteria** | | |
| E.coli | Indikator for Water Quality & Enteritis | 3-4 log<br>(99.9 -99.99%) |
| Vibrio cholera | Cholera | 3-4 log |
| Salmonella spp. | Thyphoid | 3-4 log |
| Shigella spp. | Dysentery | 3-4 log |
| **Viruses** | | |
| Rotavirus | Diarrhoea, Dysentery | 3-4 log |
| Polio Virus | Polio | inactivated, results not yet published |
| Hepatitis Virus | Hepatitis | Reduction of cases of SODIS users |
| **Protozoa** | | |
| Giardia spp | Giardiasis | 3-4 log (Infectivity of Cysts) |
| Cryptosporidium spp. | Cryptosporidiasis | 2-3 log (Infectivity of Cysts) |
| Entamoeba histolitica | Dysentery | inactivated, results not yet published |

Source: SODIS, 2002

**Picture 21. SODIS bottles**

During completely overcast days the UV-A radiation intensity is reduced to one third of the intensity recorded during a cloudless day. Burgess (2002) recommended that bottles should be left for a full day (8 hours) under partly cloudy conditions, and two consecutive days under a cloudy sky. To be safe, turbid water should also be treated an extra day longer.

The SODIS system utilizes the synergistic effects of heat, UV and reactive oxygen. This is very effective as microbes differ in sensitivity to inactivation by heat and by UV radiation, enhanced by aeration. At least for E. coli, studies have shown SODIS oxygenated water to inactivate bacteria to a level of 99.9999%, compared to 90-99% in anaerobic water. (Sobsey, 2002)

The inactivation of spore and cyst forming organisms such as protozoa and helminths needs further evaluation; however, if contaminated water reaches a temperature of at least 50°C during an hour and is aerated, this would ensure the destruction of the amoebic cysts as well as many other micro-organisms.

Advantages of SODIS:
- improves the microbiological quality without changing the taste of water
- simple in application, understanding, and replicable with low investment costs.
- saves resources and operating costs as it relies on local materials and renewable energy
- when replacing the burning of firewood, reduces deforestation and air pollution
- the bottle can be used for storing of drinking water, which is more hygienic than open pots.

Limitations:
- only small volumes (1-2 L) per bottle.
- not reliable if turbidity greater than 30 NTU*. (see appendix D.3 for turbidity test)
- no certain end-point. Difficult to be 100% sure if the pathogens have been inactivated if there is only partial sunshine, or the water is moderately turbid.
- does not improve chemically contaminated water.
- potential microbial regrowth after 1-2 days since no chemical disinfectant residual.

### 9.2.3. Sedimentation and Ceramic Filtration

The sizes of the microbes are especially important for their removal by sedimentation and different filtration methods.
- Viruses are the smallest waterborne microbes (20 to about 100 nanometres in size) and the most difficult to remove by filtration and other size exclusion methods.
- Bacteria are somewhat larger than viruses (about 0.5 to 3 micrometers) but too small to be readily removed by plain sedimentation or settling.
- Protozoan parasites are the next largest in size (most are about 3 to 30 micrometers) and only the largest ones are likely to gravity settle at appreciable rates. Most helminths (such as schistosomes) of concern in water are readily removable by settling and various filtration processes.

Overall reductions of viruses and bacteria by sedimentation rarely exceed 90%, but reductions of helminth ova and some protozoans can exceed 90%, especially with longer storage times of 1-2 days. (Sobsey, 2002) Although viruses, bacteria and the smaller protozoans are too small to gravity settle, these waterborne pathogens often attach to larger particles. Aggregated microbes, assisted by coagulation-flocculation, are easier to remove by physical processes than dispersed microbes.

The effectiveness of filtration methods in reducing microbes also varies widely, depending on the type of microbe and the type and quality of the filtration medium or system.
The filter pore sizes required to efficiently remove micro-organisms are:

- 1 to several micrometers pore size for parasites
- 0.1 to 1 micrometer pore size for bacteria
- 0.01 to 0.001 micrometer pore size (ultrafilters) for virus removal

Typically the most effective filters require advanced fabrication methods, special filter holders and the use of pressure to force the water through the filter media. These filters are usually not readily available and their costs generally are too high for household treatment in a developing region.

Ceramic filters are recommended by the WHO for use at the household level. They are simple and can be highly effective to use, and can usually be made locally. Some ceramic filters manufactured commercially in the US and UK are rated very highly, with removal of at least 99.9999% of Giardia cysts, 99.99% of bacteria, and 99.9% of viruses. (Sobsey, 2002). However, consistent quality of local made filters may be difficult to document unless testing is available to verify microbe reductions. Ceramiques d'Afrique (2005) purifiers are of the 'candle' variety; 8 cm in diameter by 14 cm high, and designed for maximum 1.0 l/h, with 99% of particles are removed down to 1.0 micron. This is an effective barrier to parasites, but not all bacteria, and definitely not virus.

Initial cost of a ceramic filter is about US $5 and replacement candles about $1. A family of 6 probably would need two units, and the candles usually need to be changed every 3 months. This translates to an initial cost of 936 KES ($12) and 624 KES ($8) on an annual basis.

If other control measures are not available, the WHO recommends the use of filtration with paper, nylon fabric, or sari cloth (fine woven cotton) as an essential intervention towards larger pathogens such as guinea worms, schistosomes, and zooplanton-associated V. cholerae (Sobsey, 2002).

### 9.2.4. Moringa Oleifera Biological Coagulation and Disinfection

Moringa oleifera is often described as a the “the miracle tree”; multi-provider of oil for cosmetic and edible purposes, natural coagulant available from the seeds, and the leaves and young pods as a nutritional green vegetable for human and animal consumption.

Scientific name: Moringa oleifera Lam. (M.oleifera).
English name: Horseradish tree (describing the taste of its roots)
Indian name: Sorogowa / Drumstick tree (describing the shape of its pods)
Swahili names: Mulonge, Mlonge, Mronge, Mrongo, Mlongo, Mzunze (Fuglie, 1999)

The Farmer’s Training Centre in Homa Bay hosts a Moringa Research and Promotion Project[6], educating farmers in the Lake Victoria region.

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[6] Moringa stenopetala, indigenous to East Africa, is also growing and promoted in the Lake region. This species has less research data available, therefore not discussed in this study.

**Picture 22. Moringa 2m tall, 8mths**

A tree native of northern India, this Moringa species is now widely cultivated throughout the tropics and is found in many countries of Africa, Asia and South America. Moringa grows rapidly from seed and cuttings even in marginal soils; 2m height with flowers and fruit obtained within the first year. It demands little attention and is hardy enough to survive prolonged periods of drought.

**Picture 23. Moringa seed pods**

Moringa oleifera (MO) has been found to be an effective natural coagulant in household water treatment as well as in community water treatment systems. MO proteins also have anti-microbial properties, demonstrated to be effective against pathogenic bacteria, some of which are antibiotic resistant.

The dual actions of MO seed powder:

A) Flocculation / coagulation

The seed kernels of MO contain significant quantities of low molecular-weight, water-soluble proteins. When the crushed seeds are added to raw water, the proteins produce positive charges and attract the predominantly negatively charged particles (such as clay, silt, bacteria, and other toxic particles). Aggregation assists the proteins bind particles into flocs, which are then easily removed by settling or filtration. As a coagulant on highly turbid water, MO is as effective as alum, however effectiveness reduces with less turbidity. (Sutherland et al, 1994)

B) Anti-bacterial disinfection

MO possesses anti-microbial properties, although the exact mechanism by which this occurs is not yet fully understood. Some bacteria cells are removed with flocculation, and also there is evidence of active MO proteins directly inhibiting bacteria growth. (Ghebremichael, 2004)

Materials needed:
- stone or mortar (common household spice crusher)
- clean plastic bottle, approximately 0.5 L size (for concentrated solution preparation)
- 20 L container or bucket x 2
- clean filter cloth

**Picture 24. Moringa seeds, with and without husk**

Three-year-old Moringa trees in the Lake Victoria region are estimated to yield 400-600 pods annually and a mature tree can produce up to 1,600 pods. (Fuglie, 1999) Each pod has 15 seeds. As a rule of thumb, one shelled seed (approx. 200 mg) is used to treat 1 L of very turbid river water, and 2 L if mildly turbid. Therefore one young tree produces at least enough seeds to treat 6000 L of highly turbid water, and a mature tree at least 24,000 L. Depending on storage conditions, seeds have about one year +/- 3 months as shelf life.

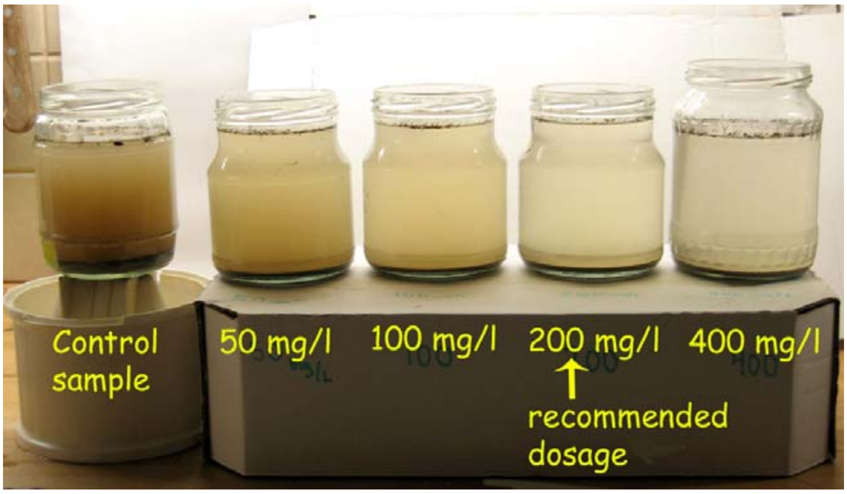
One third of the village has need for turbid water pre-treatment. Depending on tree yield, essential water pre-treatment could be supplied by 75-300 trees. It is recommended that each family grow a Moringa tree! The Orongo Widows and Orphans Self Help group already has them.

Cost:
MO trees can be cultivated very easily at the household level or in small communal nurseries, and seeds are produced within about 10 months. Initial setup otherwise requires only common household equipment, estimated to cost not more than 200 KES. The only consumable item is MO seed therefore operating cost is zero.

Efficiency:
The crushed seed powder, when mixed with water, yields water soluble proteins that possess a net positive charge. The solution acts as a natural cationic polyelectrolyte during treatment.
Ndabigengesere and Narasiah (1998) found that purified MO was just as effective as alum (with optimal dosage 1mg/l) by reducing turbidity 90% (from 105 to 10 NTU) with coagulation and settling of flocs alone. However crude extract requires a higher dosage since less than 25% of the MO powder dissolves, and introduced organic matter uses some of the particle removing capacity.

According to studies investigating the effects on Schistosoma organisms by Olsen (1987), after 4 h of flocculation, a marked decrease by removing more than 90% of Schistosoma cercariae was observed. It is suggested that since this decrease did not coincide with the changes in turbidity, that the seeds may have cercaricidal properties. Moringa seeds contain bactericidal properties and are also toxic to some protozoa. MO treatment is effective in clarifying especially highly turbid water, however does not guarantee that the raw water ends up completely (100%) free of microbiological contamination.

An experiment was performed as part of this thesis that treated water as an ordinary household should, according to procedures described in Appendix D.4. Only the listed materials were used, and the crude, non-purified MO powder. 4 different powder concentrations were tested and compared to one control. All containers contained the same highly turbid pond water. The sample water was estimated to have turbidity exceeding 150 NTU, suggesting a dosage of 200 mg/l. Sample A was tested with only 50 mg/l, B with 100 mg/l, C with 200 mg/l, and D with 400 mg/l. After one hour, these were the visual results:



**Picture 25. Moringa treatment experiment – after 1 hour clarification**

**Picture 26. The 200 mg/l and 400 mg/l samples after decanting and straining through a coffee filter.**

It can be seen that even the control became somewhat clearer, due only to settling. The remarkable improvement is seen in the treated samples, with the both C and D becoming nearly clear. (In Picture 26 are the same two samples as the right side of Picture 25). There is hardly any visible difference between the samples that were dosed 200 mg/l and 400 mg/l, therefore the recommended dosage seems to be close to optimal.

Subjectively, it appears the treated water has enough clarity to be put towards a final disinfection step of SODIS or chlorine.

Advantages:
- Cheap and easy method for developing countries (especially at household level).
- efficiency is independent of raw water pH.
- processing doesn't modify the pH, conductivity, or alkalinity of the water and hence does not cause corrosion problems.
- the active compounds still remain in presscake after oil extraction (Sutherland et al, 1994)
- water taste is not altered (unless a very high dose is added).
- environmentally sound process - low volume of sludge precipitated is biodegradable
- Coagulation experiments with on high turbidity waters (250-300 NTU) shows optimal dosage of purified active proteins to be 5 mg/l, 3 times lower than the optimal dosage of alum. Crude extract MO performed as well as alum at 15 mg/l. (Ghebremichael, 2004)
- there is no evidence of the seeds causing secondary effects in humans, especially at the low doses required for water treatment.
- drought resistant, quick maturity, perennial seed production with minimal inputs or labour.
- The seed barks and husks can be pyrolyzed to produce activated carbon, which in water treatment is a valuable adsorbent in removing colour, taste and organic matter. (Ndabigengesere and Narasiah, 1998)

Limitations:
- treated water may still carry some pathogenic micro-organisms.
- introduces organic matter, some nitrate and orthophosphate (Ndabigengesere and Narasiah, 1998). Diluted in the final treatment they are less than 1/10th the WHO guideline, so nitrate only a potential health concern if someone continually drank the concentrated solution.
- storage only about 24 hours when using crude extract – organic particles provide grounds for bacterial re-growth; unsatisfactory within distribution systems.

• Households using crude extract must prepare fresh daily. The coagulant compound is preferred in purified form, being more stable and avoiding increased organics and nutrients. However production is currently a cumbersome process requiring materials not available in individual households, and not yet economically feasible at a commercial scale.

### 9.2.5. Chlorination

Chlorine is an effective disinfectant where water is not turbid (cloudy) and the pH of the water to be treated is not alkaline (not above pH 8.0). For household water treatment, the most practical forms of free chlorine are liquid sodium hypochlorite and solid calcium hypochlorite. Bleaching powder or household bleach can be used to shock disinfect wells, but is less desirable on a regular basis because it may contain undesirable additives (detergents, fragrances, abrasives, etc), and become unstable during storage.

In Kenya, the Safe Water System (SWS) is being widely promoted by the CDC and CARE in coordination with local organisations. The SWS includes a hygiene education component and treatment with 1% liquid sodium hypochlorite solution to water stored in a household vessel to be used for drinking and for washing hands, vegetables, fruits, and utensils.

Materials needed:

- commercial chlorine solution or powder
- appropriate storage container – recommended storage vessels are either plastic or clay, with narrow-mouth and a spigot (tap) designed to minimize post-treatment contamination. Plastic vessels require lower treatment dosages and retain residual chlorine longer than clay.
- clean white cotton or polyester cloth to filter cloudy water

Cost:

- Waterguard (1% sodium hypochlorite) is available in the Kisumu area at an average price of 35 KES / 0.5 litre bottle. One bottle can treat 417 -1250 litres, depending on the source water quality and type of storage container, representing a cost of 0.08 KES / L to 0.03 KES / L.
- storage vessels (clay pot modified with spigot) 300 – 350 KES

If one bottle lasts a family 25-30 days (CARE Kenya, 2003), the annual operating cost would be 425-510 KES. This assumes a 6 person household, 3.5 L consumption pp/day (drinking, food washing), a clear well source and clay storage vessel (dosage 16ml / 20L).

Effectiveness:

The Safe Water System uses zero detectable E-coli as a process indicator. Disinfection with chlorine is not instantaneous, and time taken for different types of microbes to be killed varies widely. Bacteria, including free-living Vibrio cholerae are rapidly inactivated by free chlorine under normal conditions. According to the WHO, free chlorine generally inactivates > 4 $\log_{10}$ (>99.99%) of enteric bacteria and viruses at doses of a few mg/l and a contact time of about 30 minutes. (Sobsey 2002) In general, amoebic cysts are very resistant and require more exposure. A chlorine residual of 1 mg/l after 30 minutes will kill schistosomiasis cercariae, while 2 mg/l after 30 minutes may be required to kill amoebic cysts. The control of pathogenic protozoa and guinea worm requires efficient filtration since these organisms are rather resistant to disinfection. (CDC, 2005)

Resistance is also influenced by physical and physiological states. Microbes in the form of aggregates (clumps) are protected from being reached by chemical disinfectants. Particulate, colloidal, and dissolved constituents in water can protect microbes from inactivation by reacting with and consuming the chemical disinfectant. (Sobsey, 2002) Evaluation of the SWS in Nyanza Province showed that the microbiological quality of stored household water was significantly improved and diarrhoeal risk among children under five was reduced by 58%. (CARE Kenya, 2003)

Advantages:
- widely available and relatively affordable to most
- effective on most water borne pathogens
- easy to apply, with determination of application by smell or taste
- quick to use on large volumes, and water available within a very short time (30-60 minutes)
- residual chlorine protects against post contamination

Limitations:
- effectiveness reduced with turbid water - not appropriate if above 5 NTU
- difficult to determine appropriate dose with variability in source water - danger of overdosing affects palatability and under-dosing compromises effectiveness on pathogens.
- corrosive and volatility of chlorine requires care in handling, and use of specific containers (plastic jerri-cans and clay pots) with tight fitting lids. Not suitable for metallic containers.
- often negative perceptions to overcome - believing chlorine to be bad tasting and / or a contraceptive (CARE Kenya, 2003)
- Household chlorination is rarely fully effective in the long term (WHO, 2004 e)
- over the long term (50-70 years), trihalomethane disinfection by-products from reaction with organics can increase the risk of bladder cancer (CARE Kenya, 2003)

### 9.2.6. Chemical Flocculation and Disinfection - PuR

A flocculating agent (PuR) has been developed that with little equipment removes suspended organic matter, bacteria, viruses, parasites, and some heavy metals from surface water used for drinking. Its ingredients include ferric sulfate, bentonite, sodium carbonate, chitosan, polyacrylamide, potassium permanganate, and calcium hypochlorite, formulated in single-use powder sachets to work quickly on 10 litres of raw water with agitation. It provides precipitation, coagulation, flocculation and time released chlorination. (Allen et al, 2004)

Materials needed:
- commercial PuR® powder (4 g packet)
- plastic mixing container (10 L size)
- filter cloth – thick 100% cotton, clean with no holes
- appropriate storage container – recommended storage vessels are either plastic or clay, with narrow-mouth and a spigot (tap) designed to minimize post-treatment contamination.

Cost:
- PuR is available in the Kisumu area at a price of 5 KES / sachet. Bulk purchase (+20) from local CDC partners is 3 KES / sachet. One sachet treats 10 L, so treatment cost 0.30 KES / L.
- 1 mixing and 1 storage vessel (clay pot modified with spigot) 350 – 400 KES

The annual operating cost would be 2300 KES, assuming a 6 person household, requiring 3.5 L pp / day (drinking, food washing).

Effectiveness:
According to Souter et al (2003), PuR can achieve disinfection of >7-log bacteria, >4-log virus, and >3-log parasite reductions across a variety of water types. No Escherichia coli were detected post-treatment in 320 field water samples collected from five developing countries. In Homo Bay, 80 km from Kisumu, field testing of 14 samples initially had 0 to 9200 E. coli counts, and after treatment had 0.

Field trials by Norton et al (2003), treated 101 pond water samples contaminated with a mean of $2.9 \times 10^4$ CFU/100 ml faecal coliforms, after which 96% met WHO bacterial GV (<1 CFU/100 ml FC). Free chlorine was detected in 83% of the samples after treatment. Turbidity ranged from 6-92 NTU, with a mean of 32 NTU, and following treatment 93% of samples met the WHO turbidity guideline of <5 NTU.

A study at Johns Hopkins University evaluated the effect of PuR and observed high levels of viral inactivation during mixing prior to the settling of the formed floc. They measured free chorine concentration ranging from 0.8 mg/L after 10 to 20 s to a peak of approximately 1.2 to 2mg/L after 2 minutes. Although free chlorine concentration in the water can be variable due to water quality, the levels obtained were sufficient to inactivate 5 logs (99.999%) of different viruses. (Le et al, 2003)

**Table 14. PuR effectiveness from lab and field testing**

| **Bacteria** | **Initial (org/litre)** | **Post-Treatment** |
|---|---|---|
| E. coli | $2.0 \times 10^8$ | none detected |
| 10 common fecal bacteria | $9.2 \times 10^9$ | none detected |
| Vibrio cholerae | $1.2 \times 10^8$ | none detected |
| **Virus** | **Initial Viral Count/ml ($\log_{10}$)** | **Mean Log Reduction*** |
| Poliovirus | 7.1 | >5.0 |
| Rotavirus | 7.9 | >5.0 |
| **Cyst** | **Mean lnitial (org/litre)** | **Mean Log Reduction*** |
| Cryptosporidium parvum | $1.76 \times 10^6$ | 4.0 |
| Giardia lamblia | $1.84 \times 10^6$ | 3.6 |
| **Heavy Metal & Pesticide** | **Initial (mg/l)** | **Post- Treatment (mg/l)** |
| Chromium (III) | 1.3 | 0.0031** |
| DDT | 0.006 | 0.00034 ** |

Source: adapted from P&G, 2004 ** WHO Guideline for DDT= 0.002 mg/l; Chromium = 0.05 mg/l
* 1998 US EPA standards state water purification performance should achieve bacteria reduction of 6-log, polio and rotaviruses a 4-log reduction, Cryptosporidium and Giardia a 3-log reduction.

Overall, PuR claims to be very effective at quickly reducing turbidity and pathogens. With highly polluted sources, turbidity mitigation potentially can achieve reductions in diarrhoeal disease greater than interventions that do not reduce turbidity, as visible improvement could stimulate consumer use more than chlorine alone. However when treating relatively clear source water, PuR does not seem to show any conclusive advantage over use of sodium hypochlorite.

Advantages:
- visibly shows that water is cleaner by turbidity reduction
- effective in reducing turbidity, pathogenic organisms, organics (humic acid, DDT), and heavy metals
- procedure involves simple implements that rural residents have in their homes
- stable sachet allows for convenient handling and long-term storage

Limitations:

- Relatively high cost for poor rural areas.
- proprietary, patented product limits local production potential
- not as widely available as chlorine solution.
- With highly variable source quality, the fixed dosage may not consistently achieve free chlorine residual between 0.5 and 1.5 mg/L.

### 9.2.7. Disinfection by Natural pH Shift

A decrease of pH can create an environment intolerable to some micro-organisms. The use of naturally acidic solutions such as lime / lemon juice (citric acid, ascorbic acid), tamarind extract (tartaric acid), or vinegar (acetic acid) in water and foods are a traditional, but still useful household treatment to reduce the transmission of pathogens.

India in the "cholera season" used lime juice in water and beverages made from tamarind as prophylaxis. Salads were drenched in vinegar, and fruit salads were given a liberal dose of lime juice. (Dalsgaard et al 1997) It is documented that European sea goers and emigrants, during their 6-10 week sail across the Atlantic, were give vinegar by ship captains to add to stale water (Moberg, 1995).

Tamarind has disinfective capacity on micro-organisms. The natives of Northern Nigeria have a history of using this fruit in water clarification (Yongabi, 2005). Tamarindus indicus is a tree native to tropical Africa, and yields highly citric fruits within a firm, thin pod, containing 12–18% tartaric acid. While in Kisumu, I was shown how to make a refreshing beverage. The fruit of 2 or 3 pods was squeezed into a 1 L bottle of water, shaken vigorously for 5 minutes, and allowed to sit about 15 minutes before drinking. It was undetermined during this study however, whether this tamarind “lemonade” is used with the intention of disinfection. According to De et al (1999), tamarind proved to have antibacterial activities against test organisms that included Escherichia coli, supporting potential use as a disinfectant. A dose of 100 mg/ml (concentrated purified extract) was found effective in inhibiting growth of E.coli, independent of pH shift.

Drinking water disinfection by lowering water pH with lime juice is effective in inactivating V. cholerae and in reducing cholera risks. The WHO (Sobsey, 2002) reported that adding lime juice to water (1-5% final concentration) to lower pH levels below 4.5 reduced V. cholerae by >99.999% in 120 minutes. Lime juice also killed >99.9% of V. cholerae on cabbage and lettuce and was recommended for prevention of cholera by addition to non-acidic foods, beverages and water. The recommendation seems to be based on findings by Dalsgaard et al (1997). With initial pH values between 7.5 and 8.3, no significant reduction in CFU of V. cholerae was found after exposure to 0.5% lime juice (pH 5.6) whereas exposure to 1.0% lime juice (pH 4.4) for 120 min caused a 5-log reduction to <100 CFU/ml. A 3-log reduction of V. cholerae was found in food samples containing 3.5% and 5.0% lime juice after 120 min exposure.

The alkalinity (and buffer capacity) of source water needs to be considered in order to accurately assess the minimum concentration of lemon juice required to shift the pH. D'Aquino and Teves (1994) found that for water with an alkalinity equivalent of 200 mg $CaCO_3$/l, required 2% lemon juice concentration and 30 minutes contact time to destroy V. cholerae. A higher concentration would be required in Orongo where average alkalinity is 788 mg $CaCO_3$/l. Assuming a 2-4% concentration, that translates to 20-40 ml/L, and for a family of 6, 0.5-1 L of lime juice to treat all drinking water. This is not acceptable in terms of taste for all uses, nor very practical for volumes required. The most useful application is for the occasional refreshing cold beverage, and as a dressing over fresh salads and fruit.

### 9.2.8. Fluoride Removal

Fluoride can be successfully removed by precipitation by use of coagulants (commonly an alum-lime mix), osmosis, or ion exchange. Some amount of fluoride can be removed by aluminium sulphate (alum) coagulation and therefore can be practiced when flocculation / sedimentation / filtration are available processes. The most effective methods such as reverse osmosis and activated aluminium adsorption are more expensive and require careful control, most practical at a community water supply level. (DeZuane, 1997) Adsorption on activated carbon substrates is effective, and using bone char is a potentially low cost method. The Nalgonda technique, developed in India, has been proven as a low-cost technique which can operate on a variety of water supply options ranging from piped water supplies to hand pump units, however relies upon alum. (WHO, 2004 b)

M. oleifera proteins produce positive charges that are effective as alum in flocculating suspended particles - perhaps they are also effective in binding with negatively charged fluoride particles. Review of the literature concerning MO treatment has not found mention of testing for fluoride removal capacity, but it would be interesting to investigate further.

Results of a study by Moturi et al (2001) indicate that clay pots can reduce fluoride in drinking water, with the greatest reduction occurring after 5 days of storage. They presumed that fluoride gets adsorbed onto sites of the clay minerals contained in the pottery material, however did not determine the capacity after repeated usage. Other water storage containers (plastic, metal, or cement containers) do not reduce the fluoride content of the drinking water.

There is significant evidence that fluorosis can be delayed through the consumption of tamarind fruit, according to research by Khandare et al, (2004). There is a suggested beneficial effect of tamarind ingestion on fluoride toxicity by way of increased urinary pH, which facilitates increased fluoride excretion in urine and decreased retention of fluoride in bone. The study area borehole source water had a fluoride content of 2.77 mg/l, and subjects received 10 g of ready-to-eat tamarind fruit per day, and examined to determine the effect of tamarind intake on urinary components. The study concluded that tamarind ingestion in the diet increases fluoride excretion in urine and decreases copper and calcium excretion significantly, a beneficial effect on skeletal health of children from a fluorosis endemic area. Tamarind is indigenous to Kenya and is found in Orongo village.

Overall the best strategy for Orongo residents reducing fluoride exposure is to try offset the use of borehole water, and to alternate with other drinking sources such as rainwater. Efforts should also be made to minimize evaporative concentration in watering areas. A daily diet that includes tamarind fruit appears as it would be entirely beneficial to increase fluoride excretion. The protected shallow wells would be an appropriate source when treatment is planned (chlorine, solar pasteurization, or SODIS), or the use involves boiling (cooking, tea). Storing borehole water in clay pots perhaps has some benefit, however the 5 days required increases the risk of pathogen contamination. It must be stressed that the first priority for immediate health safety is microbiological elimination, compared to longer-term risks from fluorosis.

# 10. DISCUSSION

## 10.1. Summary of Treatment Methods

The table below summarizes the treatment methods for application at household level generally recommended to reduce faecal contamination of drinking water:

**Table 15. Household water treatment methods for microbiological reduction**

| Method | Availability & Practicality | Technical Difficulty | Cost [a] | Microbial Efficacy [b] |
|---|---|---|---|---|
| Boiling or heating with fuels | Varies [c] | Low- Moderate | Varies [c] | High |
| Solar pasteurization | High- Moderate | Low- Moderate | Low (0-$2) | High |
| Sunlight Exposure (SODIS) | High | Low- Moderate | Low (5-$7) | Moderate |
| Plain Sedimentation | High | Low | Low | Low |
| Filtration [d] | Varies [d] | Low- Moderate | Varies [d] | Varies [f] |
| Aeration | Low- Moderate | Low | Low | Low [g] |
| Adsorption (charcoal, carbon, clay, etc.) | High- Moderate | Low- Moderate | Varies | Varies with Adsorbent [h] |
| Free chlorine, NaOCl, $Ca(OCl)_2$ (SWS) | High- Moderate | Low- Moderate | Moderate – Low – ($7) | Variable to High [i] |
| pH shift with citrus juice, non-toxic acids | High | Low | Low – variable | Varies |
| Bio-coagulation, disinfection (Moringa) | High | Low - Moderate | Low | Low to Moderate [j] |
| Combined chemical systems: Coagulation and disinfection | Low - Moderate | Moderate – High | Moderate ($34) | Variable to High [k] |
| Comb. Moringa coagulation and solar pasteurization | High | Low- Moderate | Low | Variable to High [k] |

Adapted from a WHO report by Sobsey, 2002

[a] Categories for annual household cost estimates in US dollars are less than $10 for low, >$10-100 for moderate and >$100 for high. (Jan'03 US $1 = 78 KES)

[b] Categories for microbial efficacy are based on estimated order-of-magnitude or $\log_{10}$ reductions of waterborne microbes by the treatment technology. The categories are <1 $\log_{10}$ (<90%) is low, 1- 2 $\log_{10}$ (90-99%) is moderate and >2 $\log_{10}$ (>99%) is high. (Sobsey, 2002)

[c] Depends on heating method, availability and cost of fuels, which range from low to high.

[d] Different filtration technologies are available. Some (e.g., membrane filtration) are recommended for emergency water treatment). Practicality, availability, cost and microbial efficacy depend on the filter medium and its availability: granular, ceramic, fabric, etc.

[f] Depends on pore size and other properties of the filter medium, which vary widely. Some are highly efficient (>>99.9% or >>3 $\log_{10}$) for microbial removals.

[g] Aeration (oxygenation) has synergistic effects with other water treatments, such as solar disinfection with sunlight or with other processes that may oxidize molecular oxygen.

[h] Microbial adsorption efficiency is low for charcoal and carbon and high for some clays.

[i] Chlorination depends on level of organics, turbidity (<30 NTU), and pH.

[j] Moringa is most useful as a pre-treatment of highly turbid water.

[k] Varies with coagulant, dose, mixing and settling conditions and pH range.

From Table 15 above it is clear that the most promising methods that rate well on all accounts are solar pasteurization, SODIS, combined Moringa bio-coagulation and solar pasteurization, and the chlorine SWS. SODIS and chlorine are only appropriate for the less turbid sources such as shallow wells. Solar pasteurization is very effective towards all water sources, however will not clarify the stream water. The best option for those forced to use stream water is the combination system of Moringa clarification followed by the solar disinfection step.

## 10.2. Cost Comparison

Based on a family of 6, the initial starting and annual operating costs are as follows:

**Table 16. Cost comparison of selected household treatment methods**

| Treatment Method | Initial set up (KES) | Annual operating (KES) | Annual operating / income ** (%) |
|---|---|---|---|
| Solar Pasteurization | 100-200 | 100 | 0.7 |
| SODIS | 360-600 | 360 | 2.4 |
| Clay pot filter | 940 | 620 | 4.1 |
| Moringa | 0-200 | 0 | 0 |
| Chlorine SWS | 300-350 * | 425-510 | 3.3 |
| PuR | 350-400 * | 2300 | 15.3 |

* The cost of a modified storage vessel is included.

** Annual farm labourer income is estimated at 15,000 KES (see section 4.6)

The costs of treatment can be put into context given a farm labourer's annual income, assuming only one earner in the family. It would cost a household about one weeks wages to operate a SODIS system, and slightly more for chlorine SWS. Moringa and solar pasteurization can be set up with only 2 days salary, and be operated for nearly zero cost. According CDC (2001) market research, it is unlikely families will buy disinfectant if its cost exceeds 2% of the average annual household income. PuR, costing 15% of annual income, is well beyond what a household can afford on a long-term basis.

As another reference point, the cost of treating typhoid is 1000-3000 KES. (Burgess, 2002) People cannot afford to become ill either in terms of medicine or lost wages, so implementing safer drinking and handling measures makes sense from a household finance perspective.

Constructing a 45m$^3$ school rain catchment system is recommended at least in Nyaimbo to provide potable drinking water. As calculated in Figure D.4, Appendix D.1.2, this tank could supply about 325 m$^3$ of water annually. Assuming a 5 year payback period, it means about 78 KES / m$^3$ or 1.56 KES / 20 L. Orongo residents currently pay 0.5 KES / 20 L from the protected water points, which amounts to about 192 KES per year per family for essential drinking water. A community rainwater source would be about 3 times as expensive as the current improved sources, assuming full cost recovery. But since the borehole is 500 m away from Nyaimbo School, it should be worth the investment. Also, if the RWH system is kept clean treatment should not be necessary and it will be the best quality source available.

From my opinion, given all the data researched, further development of groundwater is not recommended. Shallow groundwater is at very high risk microbiologically, and deeper boreholes face high fluoride levels. Furthermore, the cost of borehole implementation itself is prohibiting. According to DHV Consulting Engineers, the cost of a 60 m borehole in Kenya in 1987 was 131,000 KES including drilling, pump, materials, and labour. More recently, Harvey et al (2003) stated hand pump projects in Kenya are high, with typical cost of a borehole being approximately 500,000 KES. This makes the total installation cost far beyond the means of most rural communities. Additional hidden costs include the cost of feasibility studies, hydrogeological surveys, community mobilization, and training. Up to 4 community

RWH systems (at 126,000 KES) could be built for the cost of one borehole. There clearly are good options available for the amounts of money that villagers already are spending.

## 10.3. Catchment and Source Protection

### 10.3.1. Water Point Considerations

10.3.1.1. Protection Zones and Site Location

If new wells are required, the aim is to locate high-yielding sites and at the same time avoid sites with a high potential for contamination by surface seepage. Especially where water supply points are located within or adjacent to settlements, there is the possibility for contamination by existing sanitation units and/or waste disposal practices. However, there needs to be greater understanding on the risk of contamination, and improved criteria for the establishment of safe distances between water source and possible contamination points. (Brikké, 2000) Shallow wells penetrate only the upper part of the groundwater body, which characteristically is of the poorest quality.

The risk for contamination is very high if there exists a latrine on higher ground than the hand pump or within 10 m, other waste within 10 m, or stagnant water within 2 m. General rules from different sources state at least 30 m is recommended, but 50 to 100 m distance from pollutant sources can be required depending on specific local conditions. What is important is the isochron, or the time that it takes pathogens to die off and the distance groundwater travels in that time. Most pathogens die off within 50 days. (WHO, 2004 a) In Orongo, it can be recommended that safety distance to latrines should be greater on the northeast side of water points, as that the general direction from which groundwater is flowing. Further investigation of hydrology is needed to determine accurate groundwater protection zones.

10.3.1.2. Proper Design

The greatest source of well contamination is from water entering the wellhead or from water moving down the outside of the casing.

- Old wells should be filled to prevent water table contamination
- A watertight seal around the outside of the casing (concrete or other compacted material) is very effective in preventing movement of water around the casing. This seal should extend from the surface approximately 1 m or more down.
- A sloping concrete apron (or other suitable material) around the well will facilitate drainage of excess water away from the well. Must also be designed so the drainage water leads some distance from the well.

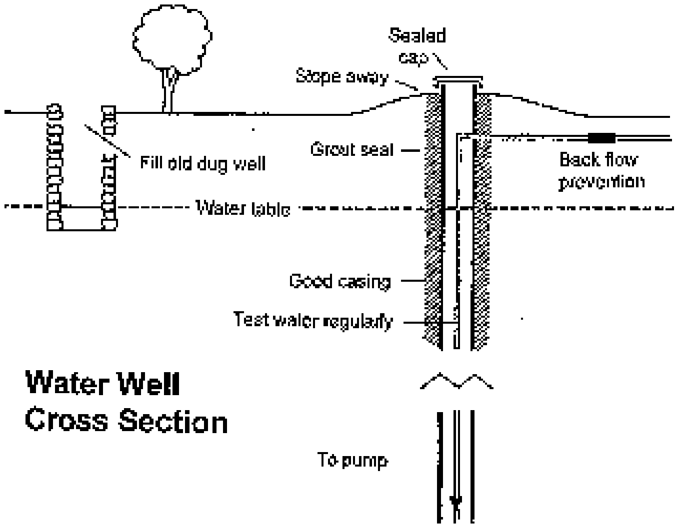


**Figure 11. Well protection points**

- In addition to the water-tight seal around the casing and the sloping apron around the well, the well-head should be constructed above ground level and precautions taken which prevent any drainage water or other contamination from entering the well.

#### 10.3.1.3. Hygienic Operation

Once well design precautions are implemented, training people in simple health safeguards is the most effective control measure.

- As a general rule, no washing or cooking should be permitted in the well area and proper design of the well head can discourage this practice. Defecation or urination in the well area should be prohibited.
- Entering into the well should also be prohibited except when required for maintenance. If this is needed, after maintenance the well should again be disinfected.
- Animals should not be permitted in the well area and their watering facilities should be at a safe distance. The well should be fenced in by at least 3m.
- The apron around the well should be kept as clean and dry as possible to prevent mud forming around the well which can be a breeding area for hookworms and other infections.
- Where a pump is not used, a community bucket and rope should be provided to prevent well contamination from unsanitary buckets used to draw water. Efforts should be made to hang the bucket up on a post and not set it on the ground.
- Where pumps are used, they should be self-priming; if not, a suitable clean water supply should be provided for priming to prevent contaminated water from being used.

The methods used to prevent contamination of a constructed well will depend strongly on the local customs and habits. Public education will be the chief mechanism in implementing these prevention measures, however, this must be co-ordinated with an adequate maintenance programme. Without proper maintenance of the well all measures to prevent future contamination may fail. (Koegel, 1985) For water supplies from a point source, the WHO recommends there should be a minimum of two analyses per year – one wet season and one dry season – to assess whether well quality varies seasonally with water level. Ideally the community should carry out regular sanitary inspections on all water supplies.

### 10.3.2. Improved Sanitation

The problem of contamination of the water supply by users through poor sanitation is widespread. According to some studies, safe disposal of children's faeces reduces childhood diarrhoea by nearly 40%. (Rehydration Project, 2004)

Use of latrines and other sanitary systems reduces the risk of faecal pollution by excluding contamination of the topsoil or ground surface so that excreta are not washed into the surface water or transported by animals. The design of latrines should also in principle ensure that there is no direct sub-surface link between the excreta and the groundwater supply, which involves taking into consideration the site, soil type and depth, and seasonal and daily water levels. (Brikké, 2000) They should be artificially lined, or at least have the pit kept within the less permeable clay layer. A minimum recommended measure of distance between latrine and water sources is 30 m. Hydrological conditions in Orongo with rapid shallow groundwater movement, would require extra precaution of up to 50 or 100 m on the northeast side of water points.

Urine separation latrines are being promoted in the Kisumu region by SANA, and based on an international ecological sanitation program being implemented by EcoSanRes (2004). Ecosan proposes sanitation that avoids using water as a means of disposal, as well as diverting the urine for use as an agricultural fertilizer. Environmentally friendly recovery of nutrients can be carried out with treated and sanitized faeces being composted and used as a soil conditioner. In rural latrines, the use of common ash is promoted to improve hygienic conditions and eliminate odour. Ash raises the pH and aids in pathogen destruction. The EcoSanRes urine separation toilets have been developed with different designs appropriate for both urban and rural applications.

### 10.3.3. Catchment protection

Prevention of contamination is the preferred approach to protecting and improving drinking supply. These are some measure that should be taken to protect the catchment.

Land use control with soil and water conservation activities can decrease turbidity by preventing sediment transport, increasing groundwater recharge, and decreasing surface flow peaks by increasing infiltration. A large proportion of soil erosion problems resulted from the expansion of cultivation into marginal areas. Reforestation programmes coupled with anti-erosion, soil and water conservation techniques, and wetland restoration are considered essential for the improvement of many water source problems. This is beyond the influence of Orongo itself, and requires a regional government approach that actively enforces measures.

The local ecosystem should be protected and natural purification capacity utilized. The overgrowth of papyrus and water hyacinths are considered to be inhibiting the flow of streams, causing flooding, and therefore villagers have made attempts to clear these. However, since the streams are so extremely polluted, this vegetation is performing a valuable cleaning service that should be replicated, not eradicated.

Unfortunately, nearly no Orongo residents are living on the shores of the Lake to utilize the cleaner stream water. On the other hand, steps should be taken to improve waterway and bank conditions upstream, to reduce erosion, animal and human contamination. Furthermore, there are wetland areas that are apparently being encroached upon. Restoration of upstream wetlands would strengthen natural purification capacity and help improve the quality of water flowing through communities such as Orongo.

## 10.4. Water Safety Plan for Handling, Storage, and Health

### 10.4.1. Treatment Hazards and Critical Control Points

According to the WHO GDWQ (2004 a), treatment and storage of household water should be developed and managed according to a Water Safety Plan that includes HACCP as a management tool. For household water, hazards and critical control points can be identified that includes source water selection and protection, water collection, water treatment and water storage, including storage vessel type and its use.

The HACCP program within a Water Safety Plan (WSP) should identify the hazards and critical control points for all steps and activities in the overall plan from source water quality to the product at the point of consumer use.

**Table 17. Hazards and Critical Control Points for Household Water Treatment**

| Type of Treatment | Source Water Hazards | Source Critical Control Point (s) | Treatment Hazards | Treatment Critical Control Points |
|---|---|---|---|---|
| *Heating to boil* with fuel | Contaminated? | Choose best available source | Adequate heat level unreached | Heat to a visible rolling boil |
| *Solar (heat) pasteurization* (cooker or reflector) in dark vessel | Contaminated? | Choose best available source | Inadequate sunlight to achieve target temperature | Target temperature sensor (thermometer or melting wax); timer, clock, sun position; monitor weather (sunny, part sun, cloudy) |
| *SODIS* - Solar Radiation in clear plastic bottles (heat + UV radiation) | Contaminated? Turbid? UV-absorbing solutes? | Choose best available source, with low turbidity and low UV-absorbing solutes | Inadequate sunlight to achieve target temperature and UV dose | Target temperature sensor (thermometer or melting wax); timer, clock, sun, monitor weather (sunny, part sun or cloudy) |
| *Settling;* plain sedimentation | Contaminated? Turbid? | Choose best source, with low turbidity | Poor settling of suspended matter | Observe for adequate turbidity reduction |
| *Filtration* methods | Contaminated? Turbid? | Choose best source, with low turbidity | Poor filtration & turbidity removal | Observe for adequate turbidity reduction |
| *Biocoagulation* & disinfection (M. oleifera) | Contaminated? Turbid? | Choose best available source | Inadequate dose Moringa and turbidity removal | Observe for turbidity reduction and adequate contact time (CT) |
| *Chlorination* | Contaminated? Cl demanding solutes? Turbid? | Choose best source, with low turbidity, low chlorine demand | Disinfection poor- inadequate dose,contact time | Observe for chlorine residual (C) and adequate contact time (T) |
| *PuR*-Chemical coagulation + chlorination | Contaminated? Turbid? | Choose best source, with low turbidity, low chlorine demand | Inadequate PuR dose, turbidity removal | Observe for turbidity reduction and adequate contact time |

Adapted from Sobsey, 2002

For the treatments discussed in this report, Table 17 above describes the important hazards (failures and deficiencies) and their critical control points that indicate process effectiveness. The critical control points are the main actions the user should take to ensure the treatment operates as effectively as intended.

### 10.4.2. Storage Vessel Critical Control Points

The application of HACCP to water storage in household vessels should address three hazards and their critical control points:
1) vessel type (appropriate versus inappropriate) - Vessel designs and types considered unsafe for sanitation reasons are those that have no cover and a wide opening allowing introduction of hands, cups, and dippers, etc.) (CDC, 2001).
2) vessel integrity (intact, damaged, parts missing, etc.)
3) vessel sanitation (cleaned, and a system to monitor and document cleaning frequency).

The most desirable water storage vessels for many household treatment and storage options are: (Sobsey, 2002)
1) easy to lift, carry, and store - between 10-25 L capacity, rectangular or cylindrical with one or more handles and flat bottoms
2) containers able to withstand rough handling without cracking – ideally made of lightweight, oxidation-resistant plastic, such as high-density polyethylene or polypropylene, for durability and shock resistance
3) easy to fill and clean, so that contact with hands in minimized
4) having a tight-fitting lid and spigot – about a 6-9 cm screw-cap opening to facilitate cleaning, but small enough to discourage or prevent the introduction of hands or dipping

utensils. Improved designs, both of plastic and clay, have a tap or spout for dispensing water and a reduced size of top opening to prevent cup insertion.

For the SODIS system, 1-2 L clear PET plastic vessels are recommended, criteria for the integrity of the vessel are specified (absence of scratches and surface damage that would reduce light penetration), and the maximum time period of water storage is specified at 2 days to avoid degradation of the microbial quality of water due to bacterial re-growth.

At every stage of domestic water management, the use of hands can directly contaminate stored drinking water through contact, or indirectly through the transfer of faecal material to utensils used. Specially designed storage containers or even household-level water treatment will likely minimize deterioration but these interventions must be combined with continued efforts to raise levels of hygiene awareness.

### 10.4.3. Improving Water and Sanitation and Improvements in Health

Many water pollution problems are due to a lack of awareness of the causes of health problems. The link between water, hygiene, and illness is not strongly perceived since water is assumed to be beneficial and cleansing rather than a potential source of infection, but many studies have quantified this obvious connection.

**Table 18: Reduction in diarrhoea mortality attributed to water supply, excreta disposal improvement**

| Type of Intervention | Number of Studies | % Reduction Median | Range |
|---|---|---|---|
| Water quality improvements | 9 | 16 | 0-90 |
| Improvements in availability | 17 | 25 | 1-100 |
| Improvements in both availability and quality of water | 8 | 37 | 0-82 |
| Improvements in excreta disposal | 10 | 22 | 0-48 |

Source: after Esrey, Feachem and Hughes, 1985

The greatest benefit is seen with improvements in both quality and availability. The relative importance of drinking-water quality to the maintenance of public health may vary with respect to a number of geographical, social, seasonal, and microbiological factors.

Promotion of household water treatment methods should always be combined with hygiene training. Three key behaviours are of greatest benefit:

- Hand washing with soap (or ash or other aid)
- Safe disposal of faeces
- Safe water handling and storage

Therefore, a combination of water treatment, safe water storage, health education, and adequate sanitation is required for lasting improvements in public health.

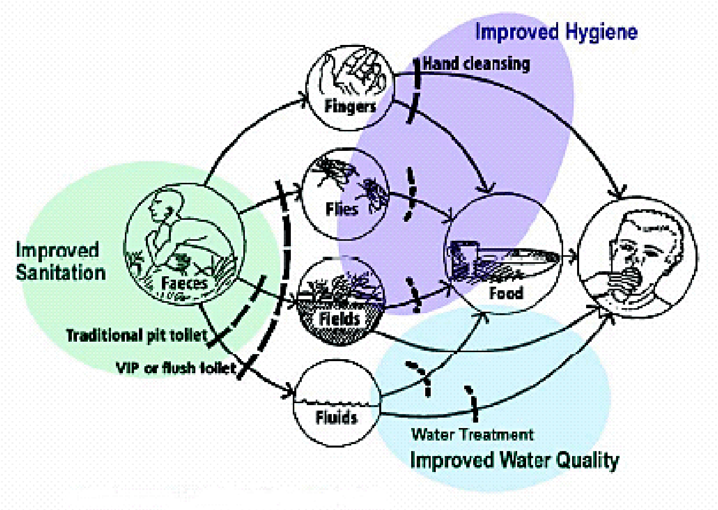


**Figure 12. Contamination Interventions** (SANDEC, 2002)

The hygiene education/training should cover the following topics:

- general household and community hygiene
- water supply hygiene
- latrine use, hygiene and maintenance
- hygienic disposal of other waste
- use and maintenance of facilities.

Results of epidemiological studies into the relationship between the quality of water supply and sanitation versus human health vary widely and there are severe methodological difficulties involved in undertaking such studies. Nevertheless there is sufficient evidence to support the conclusion that improving water supply, quality, and sanitation can have a significant impact on human health.

# 11. CONCLUSION

There are numerous pressing concerns facing Orongo village that involve water. The extreme rate of child mortality in the region indicates there are serious and even epidemic health problems, many of which are related to hygiene, poor sanitation, flooding, and water quality. It is remarkable that at least some of the solutions of clean water and better hygiene are simple, yet conditions persist that allow so many people in poor areas to be affected. The awareness of hygiene practices and low cost household treatment methods varies significantly by village and tribe, but it can be generalized that most haven't the economic means to improve their situation. The technology and improved practices exist to solve the problems of quality, safe supply, and hygiene, but social, economic, and political factors have limited this benefiting those in greatest need. Implementation of proven methods depends upon the availability and affordability of materials, ease of adaptation to local conditions and preferences, and the active participation of the community to decide what is appropriate.

Rural populations in developing areas such as Orongo often only have access to water of poor quality. Options that rely solely on time- and resource-intensive centralized solutions have failed in the past and are not likely to be implemented in the near future. Large-scale technical interventions remain infeasible due to cost, lack of electricity, treatment chemicals, and water storage capacity. The treatment of water to be safe for consumption therefore remains under the responsibility of the individual household. Resources and efforts therefore should be focused on supporting household and point of use approaches. In terms of economics, stand-alone water improvements usually do not directly pay a return. However, a healthier community is more productive, and in combination with potential surplus supply, income-generating ventures can be initiated. Long-term sustainability would then envision such ventures to provide investments into further improvements in water and community infrastructure.

Most drinking water sources are of sub-satisfactory quality. There is widespread microbiological contamination, significant in shallow wells, and extreme in surface waters. Groundwater has naturally high levels of fluoride with especially the deeper boreholes twice exceeding health standards, and can be cause for long-term concern. Residual pesticides usually do not have immediate effects and have not been tested for in the Orongo water supplies, therefore at present are an unknown risk. Availability of potable water is a serious concern in the southeast Nyaimbo school area of the village, which largely relies upon an extremely polluted seasonal stream without treatment.

A qualitative method for analysing contamination hazards and prioritizing risks was applied in Chapter 8. Control measures to minimise contamination risk for the water available to Orongo can be recommended and summarized as in Table 19 below.

**Table 19. Summary of Water Hazards and Control Measures**

| Priority | Hazards | Control Measures |
|---|---|---|
| 1 | • pit latrines discharge - poor sanitation | Improved latrine design, urine separation; hygiene education |
| | • inadequate well protection - unsealed casing or no protection at all | Seal well, ensure water drains away sufficiently, pump is in working order |
| | • inadequate treatment methods - insufficient or inconsistent | Low cost treatment; coagulate & settle turbid water before disinfection; 1hr chlorine contact time; Utilize rainwater |
| 2 | • inadequate watercourse buffer zones; soil erosion and failure of sediment traps | 10 m buffer zones, designated cattle watering areas; Land use control to preserve vegetation cover, wetland restoration |
| | • unconfined and shallow aquifer - rapid groundwater flow, recharge from streams | Properly seal shallow wells; greater safety distances from NE pollution sources |
| | • unhygienic practices - at wells, during handling and storage | Fence off from animals; prevent dirty objects entering wells or containers; hygiene education |
| 3 | • climatic and seasonal variations, natural disasters - flooding and cholera epidemic | Flood control, lagoon catchment systems |
| | • rapid variations in raw water quality - intense rainfall events | Upstream runoff control, reforestation; Backup / alternate sources or reliable treatment |
| 4 | • geology (naturally occurring chemicals) - high fluoride levels | Alternate drinking sources such as rainwater |
| | • land use changes - population pressure, intense development | Government land and water management; regional planning |
| | • topographical features - low, flat areas accumulating water; abandoned wells | Backfill unused wells; ensure shallow wells sealed |
| 5 | • agriculture - agrochemical use in catchment | Government incentives to reduce agrochemicals; awareness of good agricultural practices |
| 6 | • human access - car washing, automotive chemicals, sand harvesting | Government regulation; environmental education |

A multiple barrier approach is recommended to address the numerous contamination hazards and with the hope of preventing new cycles of contamination and reducing infection causing, water related disease. The most important aspects that villager’s in Orongo can influence in their strategy towards safe drinking water are:

**1) Repair and better protect existing wells**. Rapid access of surface water to groundwater means high vulnerability for faecal contamination. This is mostly entering the wells through casings that are improperly sealed or cracked. Maintenance measures need be taken to protect, seal, fully clean inside, and then shock disinfect the existing protected wells. Also, in at least two areas, Orongo and Nyaimbo schools, there are old collapsed wells that could be direct conduits of contamination to the aquifers. These should be properly backfilled.

**2) Adequate treatment according to source**. Given the variability in the quality of Orongo water supplies, multi-method treatments are necessary. The diagram in Figure A.2, Appendix A provides an overview of appropriate treatment options depending on the source.

Growing already within the village, Moringa is extremely appealing as a natural, low cost treatment method. It is most effective in turbid surface waters like the Luanda stream, but requires a final disinfection step to be safe for drinking. Moringa plus SODIS would provide an excellent combined natural treatment system. Protozoan parasites settle out, aided by MO flocculants. Some virus and bacteria can be bound to particles and also removed. The remaining micro-organisms can be effectively destroyed with sufficient SODIS treatment.

Widespread acceptance of the proposed treatment methods also requires further investigation and community participation to determine local perceptions towards chemical disinfectant, Moringa, and stored rainwater. Treatments with PuR on surface water, and chlorine on low turbidity water, are highly effective methods, but cost may also limit their application.

**3) Utilize better sources. Implement rainwater harvesting**. Rainwater is likely the best quality and a good potential supply depending on the number and size of storage reservoirs. As calculated in Table D.1, Appendix D.1.3, 16 large tank systems built on just the communal school and church buildings would be sufficient to provide the village with essential drinking water all year round.

**4) Prevent sources of pollution.** Conditions in the immediate vicinity such as pit latrines and activities near the water sources all influence the quality of surface and ground water. Protection involves better control of land use and activities that could contribute to contamination. Prevention is better than relying on treatment. Efforts need to be made that improve the standard of sanitation; properly sealed latrines, preferably of a urine separating design and utilizing ash to aid pathogen decomposition. Upstream anthropogenic pressures and natural environmental factors significantly affect the quality of surface waters, however a coordinated regional approach is required to address the most harmful activities in the catchment.

**5) Hygiene to prevent cross contamination.** Unhygienic practices at the water points, in handling, and during household storage are significant hazards to water quality. For example, unclean containers dipped into the wells and storage pots are practices that need to be changed through awareness building and education. Socially it appears a greater effort needs to be made to educate on the links between water, health, and hygienic practices. Both a top-up and bottom-down approach should be taken, with children educated through their schooling, and capacity building sessions that involve the village elders with communicating the issues.

The solutions exist that can provide relatively safe drinking water to all parts of Orongo village, throughout the year. These are low cost and simple methods that are replicable to other similar communities around Lake Victoria. The catchment to consumer approach is recommended to reduce water related disease. In addition to utilizing cleaner sources and treatment methods, Orongo's safe drinking water strategy involves sealing wells from in-seepage, careful handling and storage, catchment protection, and preventing new cycles of contamination by eliminating the faecal – water contact through ecological sanitation.

## 12. FURTHER RESEARCH / SUGGESTIONS FOR FUTURE WORK

A number of avenues can be suggested for further research and investigation:

• **Effectiveness of a combined Moringa flocculation / barrel filtration system**. Low cost methods are needed for treating turbid sources. One approach involves a system containing a drum for biocoagulation, a flash mixing tank, sedimentation tank, and a sand based filter system. It can treat about 150 litres / day, ideal for a household. Moringa oleifera seeds and Sclerotium of pleurotus tuberregium is being used as coagulants. This combined Moringa flocculation / barrel filtration system is being developed by Kenneth Yongabi (2005), and is very interesting for trial and potential widespread application in the Lake Victoria region. Also should test the effectiveness of the MO + SODIS system on turbid stream water.

• **Feasibility of integrated lagoon bio-systems as a means to irrigation, artificial wetland treatment, aquaculture, and flood control**. Creating a network of canals or lagoons would provide surface water catchment in the wet season, for use as irrigation in the dry season. Clarification by green plants is well known to be effective, and numerous methods and designs exist for constructed lagoons or trench systems. Significant benefits could be gained from an integrated biological system, plants that provide duck/chicken feed, waste which gives nutrients for lagoon fish farming, which in turn provides a protein source for villagers. On a large enough scale, a network of lagoons could be envisioned to help control wet season flooding, and then provide further water for irrigation. Land excavated from the lagoons would help raise the level of cultivated land and further improve food security.

• **Detailed hydro-geological survey and water balance** for Orongo Village, which incorporates the “ecohydrological” approach by recognizing ecosystem requirements. This would be required as a pre-study to a lagoon system intervention. Better understanding groundwater flow will also help determine more accurate groundwater protection zones.

• **Improved design of “first flush” device for RWH.** The tipping gutter system uses locally available materials, but it can be easily damaged or knocked out of place by animals, people, or strong wind. The floating ball requires close fitting components that might not be readily available in rural areas. A design should be simple in operation and of low cost materials.

• **In-depth quality study, ground and surface water**. Facilities and equipment for testing are very limited in Kisumu, and the chemical analysis results were of questionable reliability. A wider range of sources should be tested to include unprotected shallow wells, seasonal stream water, and the Lake, and should be done at numerous times over the year during both dry and wet seasons. Ideally a much broader range of contaminants should be tested, including agrochemicals, which can likely be of concern.

• **An improved database for decision making in water resources management.** Reliable hydrological, meteorological, geological, water quality, and land use data are at best available for limited periods and for a localized area, and usually scattered among different government organizations and NGOs. There is a need for data to be compiled into one central location where all can access and benefit from what has been done in the Lake Victoria region.

• **Sociological / household water usage study of Orongo and the area**. This should involve a household survey with detailed water usage and handling habits, consumption, demand, duties, and decision-makers.

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## 13.3. Interviews and meetings

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Jacks, Gunnar, Professor in groundwater chemistry, Royal Institute of Technology (KTH), discussion about Kenyan Lake Victoria & Rift Valley groundwater quality, 15 May 2004.

Okotto-Okotto, Joseph; Head of infromatics / Senior Cartographer, Lake Basin Development Authority, Kisumu, meeting discussing Winam Gulf catchment characteristics and boundaries, 19 January 2004.

Ombwayo, John Kagie, main Orongo village contact and representative. Weekly discussions between 15 November 2003 and 29 January 2004.

Werimo, Kenneth, Senior Researcher KMFRI, Kisumu, casual meeting at Hillbrow, 17 December 2003.

# APPENDIX ITEMS

## A. Flow Chart Overview of Thesis Structure

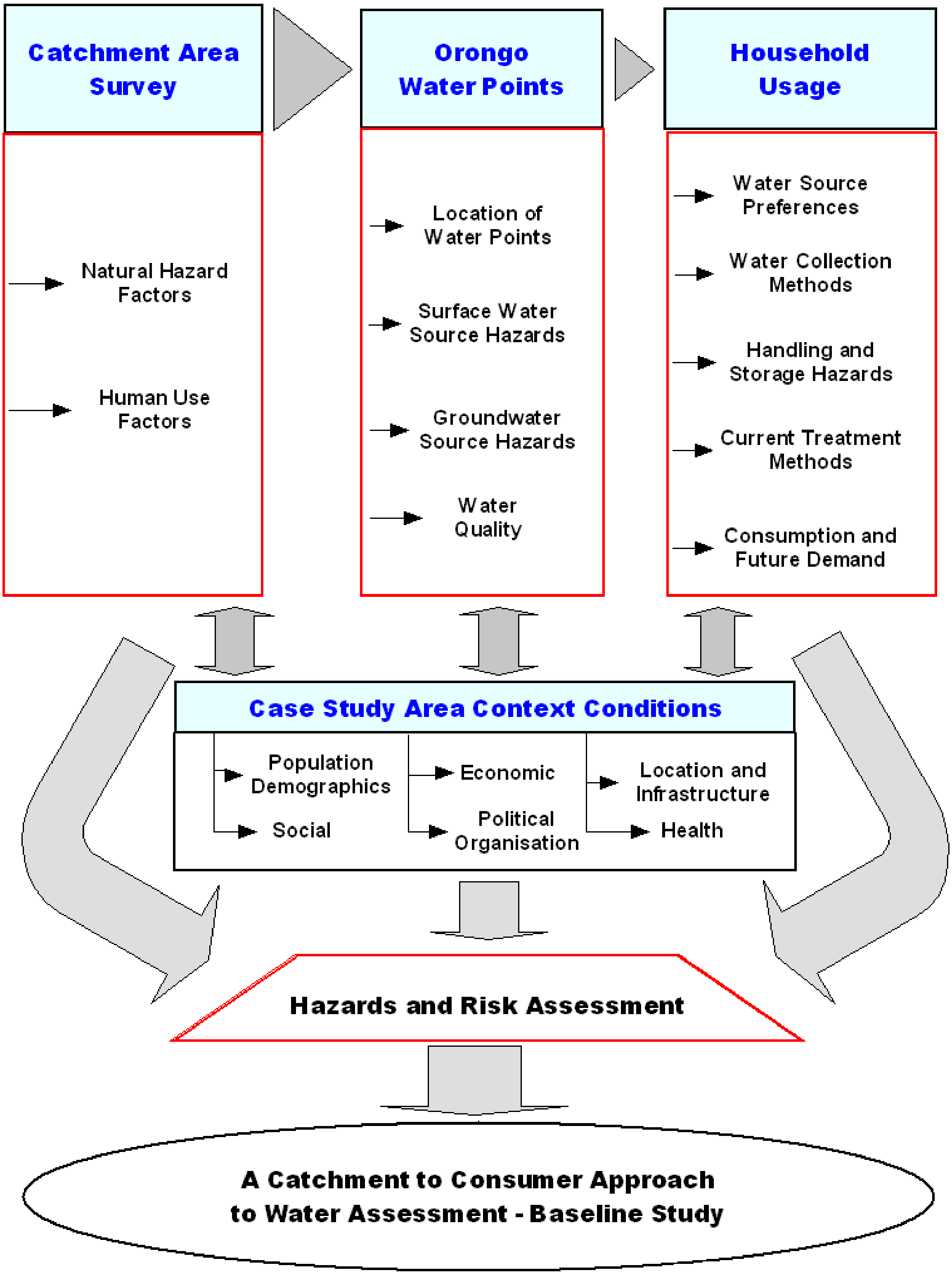
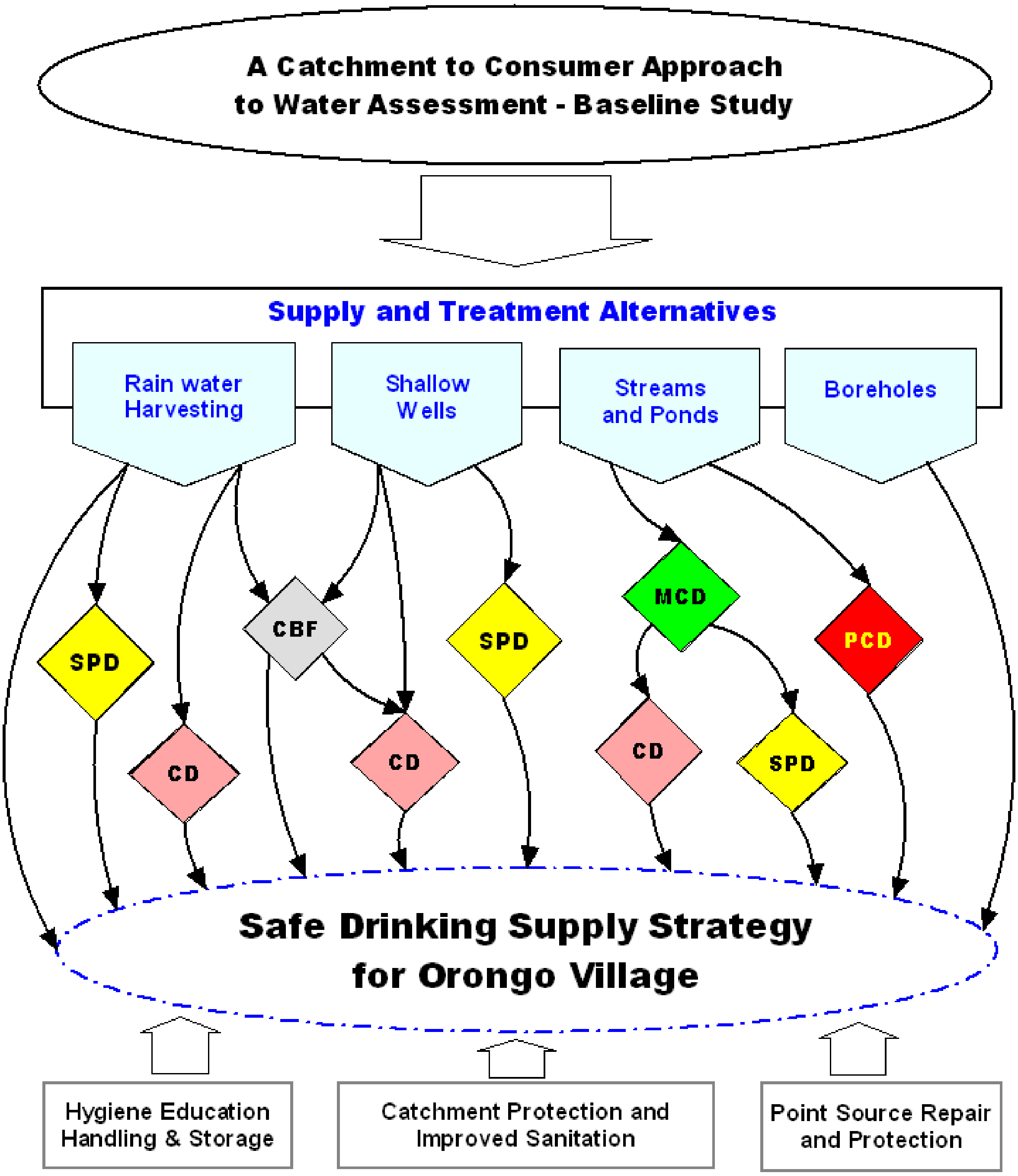


**Figure A.1. Overview of the approach for the Orongo Village baseline water assessment**



SPD = Solar Pasteurization / Disinfection
MCD = Moringa Clarification & Disinfection
CD = Chlorine Disinfection
PCD = PUR Clarification & Disinfection
CBF = Ceramic Bucket Filtration

Figure A.2. Overview of the Safe Drinking Supply Strategy for Orongo Village

# B. Definitions and Terminology

## B.1. Water Quality Terms

• *Alkalinity*: The quantitative capacity of a water solution to neutralize an acid; the ability of a solution to resist a pH change with an addition of an acid. Other anions (such as hydroxide, borates, silicates, and phosphates) can contribute to the alkalinity. It is expressed in terms of its calcium carbonate equivalent. It indicates the buffer capacity of water and a better way to estimate sensitivity to acidification than the unstable pH value (Bergelin et al, 2002).

• *Calcium carbonate equivalent*: A common basis for expressing the concentration of hardness and other salts in chemically equivalent terms to simplify certain calculations; signifies that the concentration of a dissolved mineral is chemically equivalent to the stated concentration of calcium carbonate.

• *Carbonate (Temporary) hardness*: Presence of calcium and magnesium weathered from carbonates in rock and soil, which can be precipitated by heating the water; it does not measure the sulphates and other anions. Carbonate hardness is a confusing term because it more refers to the alkalinity from the carbonates and bicarbonates.

• *Coliform bacteria*: A group of micro-organisms used as indicators of water contamination, and the possible presence of pathogenic (disease producing) bacteria.

• *Conductivity:* Related to the concentration of ions in water capable of carrying electrical current. It is a measure of the total salinity and gives an idea of a freshwater supply of nutrients, i.e. eutrophic lakes generally have a higher conductivity than oligotrophic. (Bergelin et al, 2002).

Criteria for classification of groundwater based on electrical conductivity (DHV, 1987).

| EC (µS/cm) = (mS/m) | Water Quality |
|---|---|
| <750 | good |
| 750-1250 | fair |
| 1250-2000 | poor |
| >2000 | above acceptable limits |

• *Fresh water* - contains less than 1,000 mg/l total dissolved solids.

• *Escherichia Coli (E-coli)*: A bacteria belonging to the coliform group of bacteria, and is internationally recognised an indicator of contamination of water by faecal matter. Its detection in water is a positive proof that the water contains micro-organisms capable of causing such diseases as typhoid, cholera and dysentery.

• *Hardness:* Characteristic of natural water due primarily to the presence of dissolved salts; polyvalent (valence greater than 1) cations, such as calcium (Ca+2) and magnesium (Mg+2).

Levels of hardness in terms of mg/l dissolved calcium carbonate: (Bergelin et al, 2002)

| | | |
|---|---|---|
| Soft | 0-75 | |
| Moderately hard | 75-150 | |
| Hard (alkaline) | 150 -300 | prevents soap from lathering |
| Very hard | 300+ | |

• *Non-carbonate (Permanent) hardness:* Hardness due to the calcium and magnesium concentration from sulphate-, chloride-, nitrite-, and phosphate compounds. Originating from sea salts, and will not precipitate by boiling. The excess of total hardness over total alkalinity.

• *Maximum contaminant level (MCL):* The highest level of a contaminant permissible in water in a public water system.

• *mg/l:* One milligram of a substance dissolved in a litre of water. = parts per million, or ppm

• *Nitrate* ($NO_3^-$)*:* Commonly found in well-oxygenated waters. Cause eutrophication of fresh waters and methaemoglobinaemia ("blue baby syndrome") in infants. Kenya std is 10 mg/l.

• *Nitrite ($NO_2^-$):* unstable, so high concentrations indicate sewage or anaerobic biological decomposition. Acute toxicity at 3mg/l and chronic at 0.2 mg/l, >0.5 mg/l fish die.
• *Phosphate:* orthophosphate is the most available form for plants. Healthy lakes <5 ug/l
• *Saline water:* Water containing an excessive amount of dissolved salts, usually over 5,000 mg/l.
• *Salinity:* The relative concentration of dissolved salts in water.
• *Sodium* is considered harmful in drinking water at high concentrations (even below threshold for taste) to persons suffering from cardiac, renal, and circulatory diseases. The EC MCL is set at 175mg/l, and WHO sodium guideline value is 200mg/l.
• *Sulphate* in high levels can cause diarrhoea and dehydration, particularly in infants at concentrations above 400mg/l (WHO guideline value). The USEPA recommend a limit of 250mg/L based on taste and smell. Conventional treatment does not remove sulphate. (DeZuane, 1997)
• *Total alkalinity:* Total alkalinity includes many alkalinity components, such as hydroxides, carbonates, and bicarbonates.
• *Total dissolved solids (TDS):* All of the dissolved solids in a sample of water, measured by evaporating the sample and weighing the residue. As a quick calculation, roughly = EC x 0.7.
• *Total hardness:* The sum of all hardness constituents in water, expressed as their equivalent concentration of calcium carbonate. Primarily due to calcium and magnesium in solution, but may include small amounts of metals such as iron, which can act like calcium and magnesium in certain reactions.
• *Turbidity:* A measure of the cloudiness in water, the result of finely divided particulate matter suspended in water; usually reported in arbitrary Nephelometric Turbidity Units determined by measurements of light scattering. (Culligan, 2004)
• *Volatile organic compound (VOC):* One of several organic chemical compounds characterized by its ability to evaporate readily at normal temperatures. Includes various industrial solvents and degreasers, and carbon tetrachloride.

## Water related diseases transmission

• *Water–bourne:* Mechanism of transmission in which the pathogen is in water drunk by a person or animal which then may become infected. It is important to remember that all water-bourne diseases can also be transmitted by any route that permits faecal material to reach the mouth, such as contaminated food. These diseases cannot be controlled without safe water supplies, however provision of such supplies alone will not control them.
• *Water-scarce or water-washed:* Transmission depends upon the quantity of water available more than the quality, as they are susceptible to improved hygiene and cleanliness. Eliminating the faecal-oral route by good hygiene is important since the diarrhoeal pathogens can be transmitted even when the water isn't drunk. Personal cleanliness will also reduce skin and eye infections.
• *Water-based mechanisms:* Involve pathogens that spend part of their life in an intermediate aquatic host, such as a snail. The degree of sickness depends upon the number of adult worms infecting each of the patients. The transmission link can be broken by reducing contact water carrying the organisms, and by improvements in sanitation that prevent excrement from reaching the water sources.
• *Water-related insect vectors:* Transmission by insects that breed in water or bite near water. In practice it is mostly the yellow and dengue fever mosquito vectors which breed in temporary water containers, pots and jars. If possible it is best to prevent leaking standpipes or joints that would create puddles or marshy ground, and seal water storage containers.
(Cairncross et al, 1981)

## Water related diseases

- *Cholera:* Caused by vibriocholerae bacterium and transmitted by contaminated water and seafood. (Pickering, 2001)
- *Typhoid fever:* Caused by salmonella typhi bacillus and transmitted through contaminated food or water. (Pickering, 2001)
- *Dysentery:* Two types, bacillary, caused by the shigella genus of bacteria, and amoebic, caused by free amoebae or infective cysts. Transmission is by contaminated food or water, and the cysts are especially a risk as they are resistant to stomach acid. Boiling for 10 to 15 minutes destroys the organisms. Chemical disinfection, with at least 15 minutes stand time, is effective against the bacteria and free amoeba, but 100% destruction all cysts is not guaranteed. (Netdoctor, 2004)
- *Schistosomiasis* (also called *bilharziasis* after Dr. Theodor Bilharz, a german physician who first identified the flatworm parasite) is mainly transmitted by contact with contaminated water. Free-swimming larval forms (cercariae) released from snails into the water, then infect people by penetrating directly through the skin to live in the blood vessels. Excreta or urine containing schistosoma eggs contaminates the water and spreads the disease. Eggs hatch in water to release larvae, which must within 24 hrs find a suitable snail as an intermediate host, or they will die. The parasite larvae are killed by warming water to 50 C or more for at least 5 minutes or chemical disinfection. (Thanh and Biswas, 1990)

## B.2. Description of Water Sources and Usage

- *Borehole:* Drilled well, narrow pipe casing, 50m+, with hand pump for community access.
- *Protected well*: hand or machine dug, a hand pump, with concrete walls and cover that aims to seal the well from any surface or side seepage. In Orongo, about 20m deep.
- *Rainwater harvesting*: A method of collecting rainwater, usually from a corrugated tin roof. Water is gathered into a tank or drum on the property.
- *Stream:* Collection from a tributary of the main river. In Orongo, used for bathing, washing clothes, watering cattle, and even as a drinking source of last resort.
- *Unprotected / open well*: A well dug by hand, without any sealed construction surrounding it to prevent contamination. Often the walls unsupported and can collapse after only months.

- *Water Consumption:* Volume of water actually gathered from water points.
- *Water demand:* This is an assessment of the perceived need of water by the recipient. It will vary according to the activity, expectations, economic development, and education of the individual.
- *Water extracted:* A measure of the water actually gathered at a water point and associated wastage. A measure of what is removed from a water point in total.
- *Water need:* The required water volumes based upon a series of pre-set, often qualitative assumptions and values regarding water use. There are established or accepted values such as a reasonable volume of drinking water.
- *Water use:* The sum of water extracted and water that is utilised but not gathered. Washing in a river, recreational water etc.

Water use, consumption, and extraction are measurable factors. In theory they have a real value. Need and demand are subjective values, requiring qualitative assessment in their derivation. (Clark et al, 2001)

## B.3. Other Terms and Definitions

- *Catchment:* An area of natural drainage by a river or stream, which contains a complex array of interlinked and interdependent resources and activities, irrespective of political or administrative boundaries. It is recognised that soil, water, and vegetation resources cannot be managed in isolation from one another. (Thanh and Biswas, 1990)
- *Fertility rate:* The average number of children that would be born per woman if all women lived to the end of their childbearing years and bore children according to a given fertility rate at each age. The total fertility rate is a more direct measure of the level of fertility than the crude birth rate, since it refers to births per woman. This indicator shows the potential for population growth in the country. High rates will also place some limits on the labour force participation rates for women. Large numbers of children born to women indicate large family sizes that might limit the ability of the families to feed and educate their children.
- *Infant mortality rate:* The number of deaths of infants under one year old in a given year per 1,000 live births in the same year. Often used as an indicator of the level of health in a country.
- *Population growth rate:* The average annual percent change in the population, resulting from a surplus (or deficit) of births over deaths and the balance of migrants entering and leaving a country. The rate may be positive or negative.
- *Potable water:* Water that is drinkable, safe to be consumed.
- *Child mortality rate:* The number of deaths of children under five years old in a given year per 1,000 live births in the same year. Often used as an indicator of the level of health. (World Fact Book, 2004)
- *Water resources assessment:* The determination of the sources, extent, dependability and quality characteristics of water resources, on which is based an evaluation of the possibilities for their utilization and control. (Falkenmark, 1980)

## B.4. Interpretation of Guideline Values

The most common national requirement is for drinking water of suitable quality; however, the number and specification of variables standardised have a technical and economic implication on the country. Therefore, the Kenyan government considers it not practical to standardise all variables at once. Prioritization of the variables based on their impact on the water resources and key uses of the water resources is the chosen approach.

In Kenya, there are presently no effluent discharge standards. There are, however, guidelines that are categorised depending on whether the effluent is discharged directly into a water body (in which case a full treatment is necessary), or a public sewer where pre- treatment is required. Water for drinking and fisheries is accorded top priority in Kenya. The variables proposed to be standardised in order to protect the water resources and enhance environmental health are as follows: (UNEP, 2004)

- Temperature (°C), Suspended Solids, Floating materials
- Biochemical Oxygen Demand (5-day at 20 °C). BOD is not a pollutant itself, but is a measure of organic pollution.
- Heavy metals: Lead (Pb), Mercury (Hg), Silver (Ag), Chromium (Cr), Zinc (Zn), Nickel (Ni), Copper (Cu)
- Arsenic (As), Cyanides (CN), Sulphide - Hydrogen sulphide (S), Free Ammonia (NH3), Phenolic compounds (Phenol), Nitrates (N), Phosphates (P)

Guideline values (GV) are advisory in nature, intended to be used as a basis for establishing national and regional standards based on risk assessment and prevailing socio-economic conditions. (WHO, 2004 c)

- exceeding the microbial GV indicates faecal contamination and therefore health risk
- most chemical GV set for health risk from lifetime consumption
- exceeding chemical GV for short periods does not necessarily mean water unfit for consumption
- no GV for aesthetic parameters
- no minimum concentrations specified
- do not address environmental/ecological concerns

The interpretations of WHO guideline values are as follows:

- For microbes: no significant risk of pathogen presence at infectious dose.
- For most chemicals: no significant risk to health over a lifetime of consumption.
- Some chemicals (e.g. nitrate): no significant risk of acute intoxication of vulnerable group.
- National standards may be appreciably different from guideline values.

### B.5. Abbreviations

| | |
|---|---|
| CDC | Centre for Disease Control |
| EWB | Engineers Without Borders |
| FC | faecal coliforms |
| GDWQ | WHO Guidelines for Drinking-water Quality |
| GV | guideline values |
| HACCP | hazard analysis and critical control points |
| HH | households |
| ICRAF | International Council for Research in Agroforestry |
| KES | Kenya shilling |
| KMFRI | Kenya Marine and Fisheries Research Institute |
| LBDA | Lake Basin Development Authority |
| lpcd | Litres per capita per day |
| MO | Moringa oleifera |
| NGO | Non Governmental Organisation |
| RWH | Rain water harvesting |
| SANA | Sustainable Aid in Africa International |
| SEK | Swedish kronor |
| SODIS | solar disinfection |
| SWS | Safe Water System |
| TC | total coliforms |
| $US | US dollar |
| WHO | World Heath Organization |
| WRA | water resources assessment |
| WSP | Water Safety Plan |

## C. Orongo Sanitary Survey and Well Inspection

**Table C.1. Sanitary survey and well inspection – Performed 18/12/03**

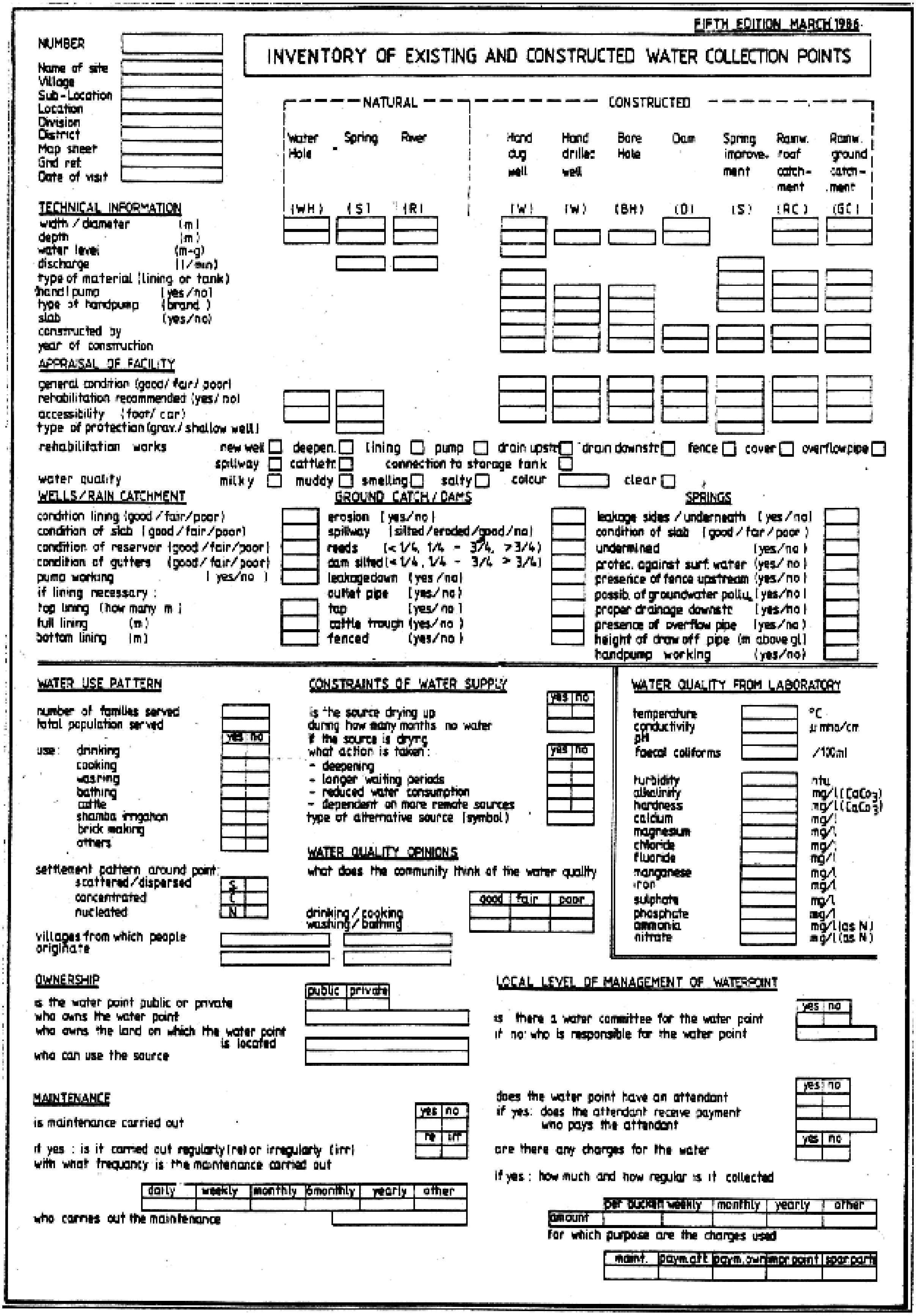
| **Name of site** | **Florence** | **Kanyawade** | **Obuso** | **Kachola** | **Kanyawade B** | **Kacholla B** |
|---|---|---|---|---|---|---|
| Map Number[1] | 1 | 3 | 4 | 5 | 2 | 6 |
| Type of source | Prot. Well | Prot. Well | Prot. Well | Prot. Well | Borehole | Borehole |
| *Technical Info* | | | | | | |
| Diameter (m) | 1 | 1 | 1 | 1 | 0.15 | 0.20 |
| Depth (m) | 15 | 17 | 11 | 12 | 70 | 70 |
| Water level (m) | 3 | 11 | 8 | 9 | ? | ? |
| Lining material | concrete | concrete | concrete | concrete | Steel pipe | Plastic pipe |
| Type handpump | Afridev | EAFW | ? | EAFW | ? | ? |
| Slab | 3m diam | 2m diameter | 2m diameter | 4x4 + walls | 3x3 +wall,roof | 2m diameter |
| Year constructed | 2000 | 2000 | 2002 | 1998 | 2001 | 2001 |
| *Appraisal of Facility* | | | | | | |
| General condition | Poor / fair | good | poor | Very good | good | Good |
| Repair required | y- Cracks | Yes | Pump broke | Yes | no | No |
| Lining condition | P- holes | fair - holes | Poor - holes | Fair – holes | good | Good |
| Slab condition | fair | good | poor | good | good | Good |
| Pump working | yes | yes | no | yes | yes | Yes |
| Quality perceived | Bit cloudy sediments with flood | Very clear | Very cloudy foul smell, floating bits | Clear, salty | V.clear, egg smell, salty, considered OK | Very clear, considered village best |
| *Water Use Pattern* | | | | | | |
| Use | Drink+oth | Drink+other | Drinking + | Drinking + | drinking | Drinking |
| # Families served | 30-40 | 50-100 | 40 | 30-50 | 50-100 | 50-100 |
| Supply constraints | Turbid with flood | Low during dry season | Low during dry season | Dry 2-5mths dry season | no | No |
| Area risk conditions | No fence protection | No fence, latrine 20m | Stale water, open cover, no fence | Water log ground | Latrine 30m, across road | Flood water go over slab, latrine 50m |
| *Ownership* | | | | | | |
| Owner of w.point | Women & orphan Gr | Consolotta Akuyo | Public | Catholic church | St. Meshad Church | Protestant church Chrst |
| Who can use | community | community | community | All, but lock | community | community |
| Responsibility | Florence | Consolotta | PeterOdunga | Church mbr | attendant | PatricObong |
| Charge / fee | 0.50 / 20L | 0.50 / 20L | No | 0.50 / 20L | 0.50 KES/ 20L | 0.50 / 20L |
| Purpose of fee | repairs | Collect if need repair | -- | Maintenance attendant | Repairs, but also to widows | maintenance |
| Recent repairs | no | Pump 2002 | no | No | no | No |

| **Name of site** | **Phillip Ayodo** | **Morris Abour** | **Bernard Ocholla** | **Kalleb Oswami** | **Dalmars Apiyo** | |
|---|---|---|---|---|---|---|
| Map Number[1] | 7 | 8 | 9 | 10 | 11 | 12 - 16 |
| Type of source[2] | Open Well | Open Well | Open Well | Open Well | Open dug well | P/open wells |
| *Technical Info* | | | | | | |
| Diameter (m) | 0.5-1 | 0.5-1 | 1-1.5 | 1-1.5 | 3 | |
| Depth (m) | 5-6 | 5-6 | 5 | 5 | 6 | Various |
| Water level (m) | 5 | 5 | 3 | 3-4 | ? | |
| Quality perceived | ? | bit clear | floating bits | salty | considered OK | |
| Area conditions | Home 2m | Home 2m | Open pit | Open pit | Latrine 30m | |

[1] All wells are identified on the Orongo Village map in Chapter 1.1.

[2] The unprotected open wells all are basically open holes in the ground, clay walls that have to be dredged out every few months, no fences (except for Dalmars Apiyo), and at best a mound of dirt with a few strips of wood that slightly narrows the opening.

**Table C.2. Water source inventory and sanitary survey template** (DHV Consulting Engineers, 1987)



FIFTH EDITION MARCH 1986

INVENTORY OF EXISTING AND CONSTRUCTED WATER COLLECTION POINTS

NUMBER

Name of site
Village
Sub-Location
Location
Division
District
Map sheet
Grid ref
Date of visit

| NATURAL | | | CONSTRUCTED | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Water Hole | Spring | River | Hand dug well | Hand drilled well | Bore Hole | Dam | Spring improvement | Rainw. roof catchment | Rainw. ground catchment |
| (WH) | (S) | (R) | (W) | (W) | (BH) | (D) | (S) | (RC) | (GC) |

TECHNICAL INFORMATION
width / diameter (m)
depth (m)
water level (m-g)
discharge (l/min)
type of material (lining or tank)
hand pump (yes/no)
type of handpump (brand)
slab (yes/no)
constructed by
year of construction

APPRAISAL OF FACILITY
general condition (good/ fair/ poor)
rehabilitation recommended (yes/ no)
accessibility (foot/ car)
type of protection (grav./ shallow well)

rehabilitation works new well ☐ deepen. ☐ lining ☐ pump ☐ drain upstr ☐ drain downstr ☐ fence ☐ cover ☐ overflowpipe ☐
spillway ☐ cattletr. ☐ connection to storage tank ☐

water quality milky ☐ muddy ☐ smelling ☐ salty ☐ colour ☐ clear ☐

WELLS / RAIN CATCHMENT
condition lining (good / fair / poor)
condition of slab (good / fair / poor)
condition of reservoir (good / fair / poor)
condition of gutters (good / fair / poor)
pump working (yes/no)
if lining necessary :
top lining (how many m)
full lining (m)
bottom lining (m)

GROUND CATCH / DAMS
erosion (yes/no)
spillway (silted / eroded / good / no)
reeds (< 1/4, 1/4 - 3/4, > 3/4)
dam silted (< 1/4, 1/4 - 3/4 > 3/4)
leakagedown (yes / no)
outlet pipe (yes/ no)
tap (yes/ no)
cattle trough (yes/ no)
fenced (yes/no)

SPRINGS
leakage sides / underneath (yes / no)
condition of slab (good / fair / poor)
undermined (yes/ no)
protec. against surf. water (yes/ no)
presence of fence upstream (yes/ no)
possib. of groundwater pollu. (yes/ no)
proper drainage downstr. (yes/ no)
presence of overflow pipe (yes/ no)
height of draw off pipe (m above gl)
handpump working (yes/no)

WATER USE PATTERN
number of families served
total population served

| | yes | no |
|---|---|---|
| use: drinking | | |
| cooking | | |
| washing | | |
| bathing | | |
| cattle | | |
| shamba irrigation | | |
| brick making | | |
| others | | |

settlement pattern around point:

| | |
|---|---|
| scattered / dispersed | S |
| concentrated | C |
| nucleated | N |

villages from which people originate

CONSTRAINTS OF WATER SUPPLY

| | yes | no |
|---|---|---|
| is the source drying up | | |
| during how many months no water | | |

if the source is drying
what action is taken:

| | yes | no |
|---|---|---|
| - deepening | | |
| - longer waiting periods | | |
| - reduced water consumption | | |
| - dependent on more remote sources | | |
| type of alternative source (symbol) | | |

WATER QUALITY OPINIONS
what does the community think of the water quality

| | good | fair | poor |
|---|---|---|---|
| drinking / cooking | | | |
| washing / bathing | | | |

WATER QUALITY FROM LABORATORY

| | | |
|---|---|---|
| temperature | | °C |
| conductivity | | μ mho/cm |
| pH | | |
| faecal coliforms | | /100ml |
| turbidity | | ntu |
| alkalinity | | mg/l (CaCo3) |
| hardness | | mg/l (CaCo3) |
| calcium | | mg/l |
| magnesium | | mg/l |
| chloride | | mg/l |
| fluoride | | mg/l |
| manganese | | mg/l |
| iron | | mg/l |
| sulphate | | mg/l |
| phosphate | | mg/l |
| ammonia | | mg/l (as N) |
| nitrate | | mg/l (as N) |

OWNERSHIP

| | public | private |
|---|---|---|
| is the water point public or private | | |

who owns the water point
who owns the land on which the water point is located
who can use the source

LOCAL LEVEL OF MANAGEMENT OF WATERPOINT

| | yes | no |
|---|---|---|
| is there a water committee for the water point | | |

if no: who is responsible for the water point

MAINTENANCE

| | yes | no |
|---|---|---|
| is maintenance carried out | | |

| | re | irr |
|---|---|---|
| if yes : is it carried out regularly (re) or irregularly (irr) | | |

with what frequency is the maintenance carried out

| daily | weekly | monthly | 6monthly | yearly | other |
|---|---|---|---|---|---|
| | | | | | |

who carries out the maintenance

| | yes | no |
|---|---|---|
| does the water point have an attendant | | |
| if yes: does the attendant receive payment | | |

who pays the attendant

| | yes | no |
|---|---|---|
| are there any charges for the water | | |

if yes : how much and how regular is it collected

| | per bucket | weekly | monthly | yearly | other |
|---|---|---|---|---|---|
| amount | | | | | |

for which purpose are the charges used

| maint. | paym.att | paym.own | impr point | spar parts |
|---|---|---|---|---|
| | | | | |

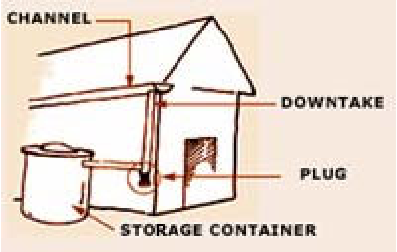
## D. Construction Guidelines & Treatment Procedures

Though simple in concept, application of the technology can be sophisticated. Firstly, in regions where rain falls only during certain months, the system should be designed so as to use the first rains for cleansing the roof. And most problems with the use of rooftop RWH derives from improper storage techniques. At a minimum, the tanks must be impermeable, closed containers, located away from sources of contamination, and the means to extract water must be sanitary.

### D.1. Rooftop Rainwater Harvesting

Components of a rainwater harvesting system:
1. A surface that directly receives rainfall and provides water to the system, such as a roof made of galvanized iron or corrugated sheets.
2. Coarse mesh at the roof outlet to prevent the passage of debris into the gutter or tank.
3. Channels all around the edge of a sloping roof to collect and transport rainwater to the storage tank. Gutters can be semi-circular or rectangular and could be made using locally available material such as plain galvanized iron sheet, folded to required shapes. Semi-circular gutters of PVC material can be readily prepared by cutting those pipes into two equal semi-circular channels. The size of the gutter should be according to the flow during the highest intensity rain. It is advisable to make them 10-15 % oversize. Gutters need to be supported so they do not sag or fall off when loaded with water. The way in which gutters are fixed depends on the construction of the house.
4. Conduits or drainpipes, to carry rainwater from the rooftop area to the tank. Conduits can be of any material like polyvinyl chloride (PVC) or galvanized iron, materials that are commonly available. Tables should be referred to that give the right diameter of pipe required for draining out rainwater based on rainfall intensity and roof area. Rainfall intensity data was not found, but is critical for optimally sizing all elements of the system.

5. A first flush device is a valve or some other devise that fits to the drainpipe somewhere between the gutter outlet and the storage vessel inlet to ensure that runoff from the first spell of rain does not enter the system. This is necessary since the first moments of rain carry a relatively larger amount of pollutants from the air and roof surface.



Source: CSE, 2004

6. Ideally some type filter to remove suspended pollutants from the rainwater. A filter unit is a chamber filled with filtering media such as fibre, coarse sand and gravel layers to remove debris and dirt from water before it enters the storage tank.
7. Storage tanks can be constructed in various ways. Some maintenance measures like cleaning and disinfection are required to ensure the quality of water stored in the container.
Shape: Cylindrical, rectangular and square.
Material of construction: Reinforced cement concrete (RCC), ferrocement, masonry, plastic (polyethylene) or metal (galvanized iron) sheets are commonly used.
Position of tank: Depending on space available, these tanks could be constructed above ground, partly underground or fully underground.
Size: The fewer the annual rainy days or longer the dry period, the larger the storage tanks needed.

### D.1.1. First Flush Devices

The simpler ideas are based on a manually operated arrangement whereby the inlet pipe is moved away from the tank inlet and then replaced again once the initial first flush has been diverted. This method has obvious drawbacks in that there has to be a person present who will remember to move the pipe. There are two general types of first-flush devices that are popularly used on RWH systems:

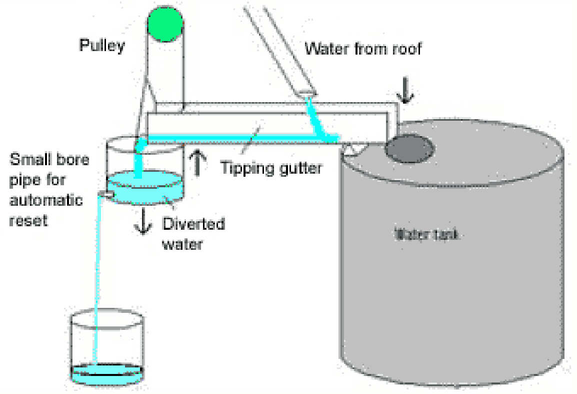


**Figure D.1. Tipping gutter first flush system** (ITDG, 2004)

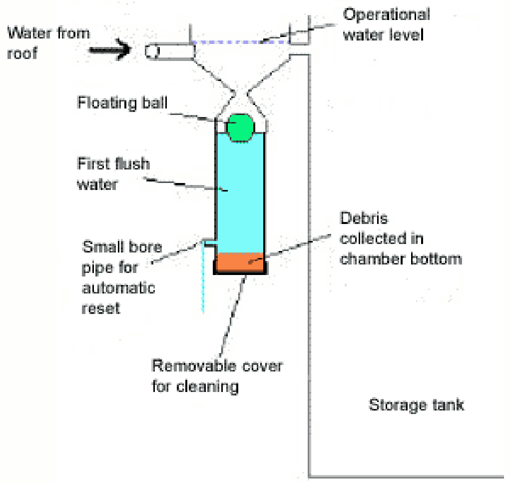


**Figure D.2. Floating ball first flush system**

a) Tipping gutter: The most common system (as shown in Figure D.1) uses a bucket that accepts the first flush and the weight of this water off-balances a tipping gutter that diverts the water back into the tank. The bucket then empties slowly through a small-bore pipe and automatically resets. The quantity of water that is flushed is dependent on the force required to lift the guttering. This can be adjusted to suit the needs of the user. This works on the theory that, if sized correctly (for example: 5L capacity per 10 $m^2$ of roof area), then the rainwater that is sent to the storage vessel will be essentially free of contaminates and debris.

b) Floating ball: This system relies on a floating ball that forms a seal once sufficient water is diverted (see Figure D.2). The seal is usually made as the ball rises into the apex of an inverted cone. The ball seals the top of the 'waste' water chamber and the diverted water is slowly released, as with the bucket system above, through a small bore pipe. Further investigation is required to determine the appropriate sizing, depending on rainfall intensity and roof area.

### D.1.2. Sizing the Storage Tank System

Usually, the main calculation carried out by the designer when planning a domestic RWH system will be to size the storage tank correctly to give adequate capacity. The storage requirement will be determined by a number of interrelated factors. They include:

- local rainfall data and weather patterns.
- user numbers and consumption rates
- size of roof
- runoff coefficient

The style of rainwater harvesting i.e. whether the system will provide total or partial supply will also play a part in determining the system components and their size. All calculations relating to the performance of rainwater catchment systems involve the use of runoff coefficients to account for losses due to spillage, leakage, catchment surface wetting, and evaporation, which will all contribute to reducing the amount of runoff. (Runoff coefficient for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface). Rainfall intensity is usually the critical factor with wash off storm events, and in appropriate design.

Outlined below are 2 different methods for sizing RWH system components. Based on the methods outlined by ITDG (2004), Nyaimbo School is used as an example.

**Method 1 – Demand side approach**

A very simple method is to calculate the largest storage requirement based on the consumption rates, occupancy of the building, and supply to last average dry periods.

Consumption per capita per day, C = 3.5 litres (drinking only)

Number of people to be served, n = 310 Longest average dry period = 25 days

Daily consumption = C x n = 1085 litres Storage requirement, T = 1085 x 25 = 27,125 litres

This method assumes sufficient rainfall and catchment area, and is therefore only applicable in this situation. It is a simple method for acquiring rough estimates of tank size.

**Method 2 – Supply side approach**

In low rainfall areas or areas where the rainfall is of uneven distribution, more care is needed to size the storage properly.

During some months of the year, there may be an excess of water, while at other times there will be a deficit. If there is enough water throughout the year to meet the demand, then sufficient storage will be required to bridge the periods of scarcity. As storage is expensive, this should be done carefully to avoid unnecessary expense. This is a common scenario in many developing countries where monsoon or single wet season climates prevail.

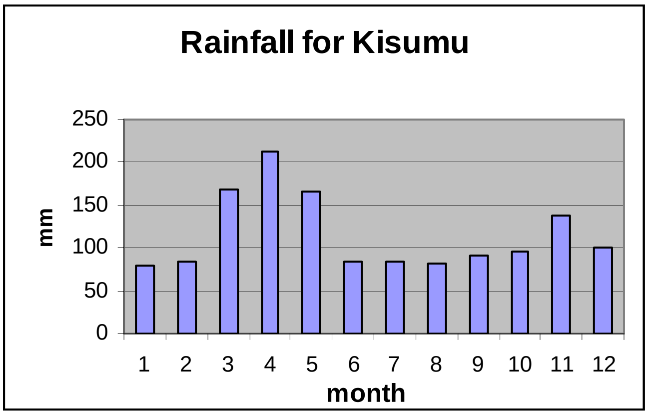


**Figure D.3. Average monthly rainfall in Kisumu 1938-1990** *** (Source: World Meteorological Organization)

| Demand | Supply |
|---|---|
| Number of staff: 10<br>Staff consumption: 3.5 lpcd*<br>Students: 300<br>Student consumption: 3 lpcd<br>Total daily demand: 935 litres | Roof area: 300m$^2$ (collecting between two buildings)<br>Runoff coefficient** (for new corrugated GI roof): 0.9<br>Average annual rainfall: 1388 mm per year<br>Daily available water (potential if all is collected) =<br>(300 x 1388 x 0.9) / 365 = 1026.7 litres |

* lpcd – litres per capita per day. It is assumed that adults would use 3.5 L, and children on average 3L. Actual school consumption would be less, but there is allowance for some use as a communal source even outside of school hours.

** Run-off coefficient for corrugated metal sheets is 0.7- 0.9, depending on slope. It takes into consideration losses due to percolation, evaporation, etc. (ITDG, 2004)

*** Kibos is closer to Orongo, but Kisumu was the only data found with monthly rainfall.

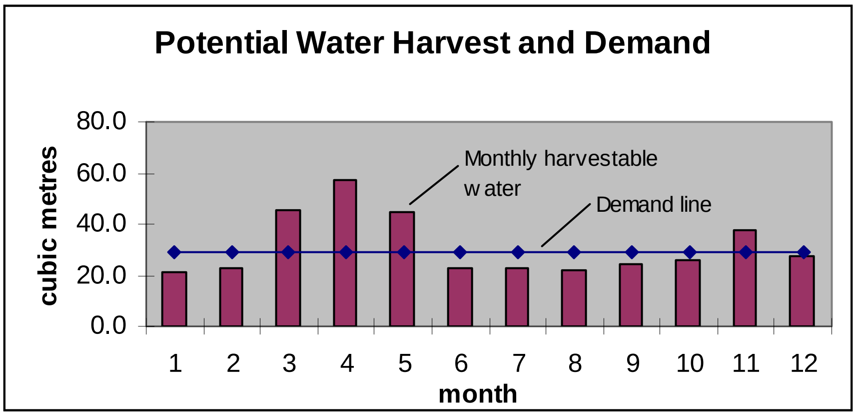


Figure D.4 shows the comparison of water harvested and the amount that can be supplied to the school using all the water that is harvested. The first month that the rainfall on the roof meets the demand is March.

**Figure D.4. Comparison of harvestable water and demand each month.**

If we therefore assume that the tank is empty at the end of February we can form a graph of cumulative harvested water and cumulative demand and from this we can calculate the maximum storage requirement for the school.

Cumulative volumes ($m^3$)

| | Supply | Demand |
|---|---|---|
| Mar | 45.6 | 29.0 |
| Apr | 103.1 | 58.0 |
| May | 148.2 | 87.0 |
| Jun | 171.2 | 116.0 |
| Jul | 194.1 | 145.0 |
| Aug | 216.0 | 174.0 |
| Sep | 240.3 | 203.0 |
| Oct | 266.0 | 232.0 |
| Nov | 303.5 | 261.0 |
| Dec | 330.8 | 290.0 |
| Jan | 352.1 | 319.0 |
| Feb | 374.8 | 348.0 |

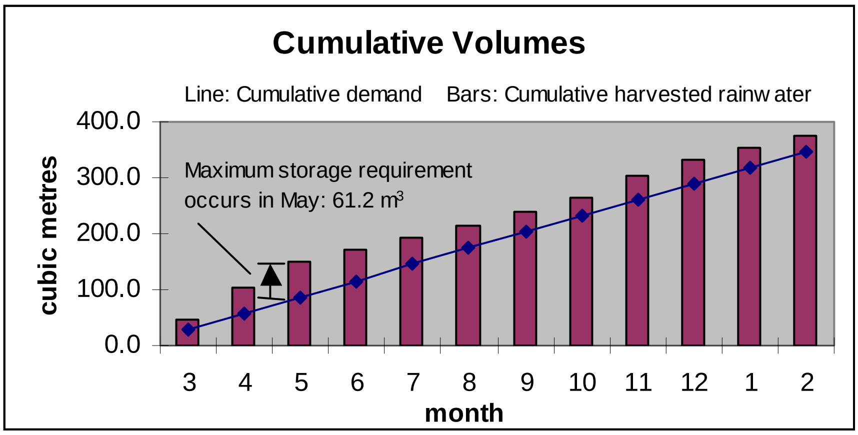


**Figure D.5. Predicted cumulative inflow and outflow from the tank.**

The maximum storage requirement (supply less demand) occurs in May with 61.2 $m^3$. This water will have to be stored to cover the shortfall during the dry period. In this situation, excess supply means some water can be afforded to spill over, and a smaller tank could be used. Using a spreadsheet, figures were adjusted and calculations showed that a reservoir of 35$m^3$ is the minimum at which to ensure a full year supply. However, sensitivity analysis on the demand figures show that if demand increases just 10%, water will run out in December, and maximum storage required would be 51$m^3$. Therefore a storage tank of 45$m^3$ should give margin to allow for some extra consumption, and carry through the dry seasons.

Although annually quite consistent, rainfall has high variability from day to day, and from season to season. More detailed data is required to better ascertain the rainfall pattern locally, and allow more accurate definition and optimization of RWH system parameters.

### D.1.3. Potential RWH Supply in Orongo

The International Development Research Centre, based in Canada, evaluated studies on rooftop RWH from more than six countries in Africa and Asia, plus Palestine over the past thirty years. The main findings indicate that all of the projects demonstrated an enormous potential from rainwater harvesting. Even in Gaza where annual rainfall ranges from 250 to 400 mm per year, systems could produce enough clean water for drinking, cooking and hand washing needs of a family of six so long as appropriate storage systems were made available. (Brooks et al, 2001) The same potential is true for residents of Orongo. As summarized in Table D.1 below, 16 RWH tanks at communal buildings can theoretically provide drinking water to the entire village and up to 3560 people depending on tank sizes.

**Table D.1. Population groups and calculated communal RWH storage requirements**

| Building | People served * | Required Storage size ($m^3$) , number | | Notes: | Capacity Extra ** |
|---|---|---|---|---|---|
| Nyaimbo Primary School a) | 620 | 35-55 | 2 | *** maximum 650 people with two tank sizes of $55m^3$ shared between between three buildings | 30 |
| Nyaimbo Primary School b) | | | | | |
| Nyaimbo Primary School c) | | | | | |
| Nyaimbo Primary School d) | 120 | 25 | 1 | 1 tank shared between 2 buildings | 0 |
| Nyaimbo Primary School e) | | | | | |
| Alara New Aposelic Church | 45 | 10 | 1 | max capacity | 0 |
| Buoye School a) | 310 | 45 | 1 | | 0 |
| Buoye School b) | 310 | 45 | 1 | | 0 |
| Buoye Catholic Church a) | 180 | 20-45 | 1 | lowest monthly harvest ($19m^3$/mth and $15m^3$/mth) meets demand | 65 |
| Buoye Church b) | 130 | 15-40 | 1 | | 70 |
| Kanyawade Catholic Church | 180 | 20-45 | 1 | $45m^3$ has capacity to serve 245 | 65 |
| Kanyawade Apostle Church | 130 | 15-40 | 1 | $40m^3$ has capacity to serve 200 | 70 |
| central Marketplace | 310 | 12-35 | 3 | 3 tanks $35m^3$ supplies 540 people | 230 |
| Orongo School a) | 310 | 35-55 | 1 | assume 300 children consume 3L | 15 |
| Orongo School b) | 310 | 35-55 | 1 | $35m^3$ works, $45m^3$ gives margin. | 15 |
| Kacholla Catholic Church | | | | under construction | |
| Kacholla Church of Christ | | | | near borehole - not urget | |
| Orongo Church | 45 | 10 | 1 | max capacity | 0 |
| **Totals** | **3000** | | **16** | | **560** |

* Arbitrary assignment bases on best estimate

** enough water for greater number of people supplied if constuct the larger tank size

*** Assume 3.5 lpcd consumption in all calculations, except the schools where 3 lpcd for children.

From an individual household perspective, potentially 75% (80 $m^3$ out of 110 $m^3$) of a six-person family's basic water needs (50 lpcd) can be met from a single RWH system. And based on calculations as in Appendix D.1.2, one tank of 12 $m^3$ would be sufficient to supply the entire year if the family manages their water consumption with 35 lpcd. However at the village scale, since coverage of metal roofs is about 50%, household RWH would likely provide only 1/3 (1095 people) of the basic needs. See bottom of Table D.2 below. The rate of conversion from grass to CGI roofs is an unknown factor that would increase this, but building 500 or more small tanks seems economically inefficient.

**Table D.2. Potential rainwater harvest from Orongo communal buildings and households**

| Building | Length (m) | Width (m) | Roof Area (m$^2$) | Max. Harvest Potential (m$^3$) | Notes: |
|---|---|---|---|---|---|
| Nyaimbo Primary School a) | 25 | 8 | 200 | 249.8 | *Priority for RWH*. grades 1-8, approx 300 students in 5 buildings. 10m from Luando stream. |
| Nyaimbo Primary School b) | 25 | 8 | 200 | 249.8 | |
| Nyaimbo Primary School c) | 25 | 8 | 200 | 249.8 | |
| Nyaimbo Primary School d) | 8 | 8 | 64 | 79.9 | |
| Nyaimbo Primary School e) | 8 | 8 | 64 | 79.9 | |
| Alara New Aposelic Church | 8 | 6 | 48 | 60.0 | next to borehole |
| Buoye School a) | 40 | 8 | 320 | 399.7 | verbal description |
| Buoye School b) | 40 | 8 | 320 | 399.7 | verbal description |
| Buoye Catholic Church a) | 26 | 10 | 260 | 324.8 | verbal description |
| Buoye Church b) | 23 | 9 | 207 | 258.6 | verbal description |
| Kanyawade Catholic Church | 26 | 10 | 260 | 324.8 | next to borehole |
| Kanyawade Apostle Church | 23 | 9 | 207 | 258.6 | |
| central Marketplace | 70 | 8 | 560 | 699.6 | approx 6 buildings |
| Orongo School a) | 30 | 10 | 300 | 374.8 | approx. 150m from |
| Orongo School b) | 30 | 10 | 300 | 374.8 | Kanyawade borehole |
| Kacholla Catholic Church | | | | 0.0 | under construction |
| Kacholla Church of Christ | 8 | 6 | 48 | 60.0 | near borehole |
| Orongo Church | 8 | 6 | 48 | 60.0 | verbal description |
| **Total Supply from Communal Buildings** | | | 3606 | **4504.6** | |
| | | | | | |
| typical House | 8 | 8 | 64 | 79.9 | approx 50% of HH have CGI roofs, but no gutters |
| number of Households (est.) | Buoye | 160 | 5120 | 6395.9 | |
| | Orongo & Nyaimbo | 340 | 10880 | 13591.3 | |
| **Total Supply from Households** | | | | **19987.2** | |

| | | | |
|---|---|---|---|
| Annual average Rainfall (mm) | 1388 | Orongo population 2003 (est.) | 3000 |
| Rainfall Coefficient | 0.9 | popln. 2018 (2.5% annual growth) | 4345 |

| **Water Consumption** | **lpcd** | **per yr (m$^3$)** | **total village per year (m$^3$)** 2003 | 2018 | | **no. people supplied** communal | households |
|---|---|---|---|---|---|---|---|
| Drinking, rinsing food | 3.5 | 1.3 | **3832.5** | **5550.6** | | **3526** | **15646** |
| Cooking | 1.5 | 0.5 | 1642.5 | 2378.8 | | | |
| Washing & personal hygiene | 45.0 | 16.4 | 49275.0 | 71364.9 | | | |
| **Total Consumption** | 50.0 | 18.3 | **54750.0** | **79294.3** | | **247** | **1095** |

For simplicity, future consumption assumes the same per capita volume as today. It is estimated that 5,550 m$^3$ will be required for essential drinking, and nearly 80,000m$^3$ annually to provide 4,345 people with basic water needs 50 lpcd. The total volume is likely underestimated, as washing and other domestic use usually increases as supply becomes more convenient and standard of living improves.

Ideally Orongo should aim to utilize rainwater as a partial source. This type of pattern provides for partial coverage of the water requirements of the user during the whole of the year. Families could use rainwater to meet only the high-quality needs, such as drinking or cooking, while other needs, such as bathing and clothes washing, are met by a water source with a lower quality.

## D.2. Solar Pasteurization

Contaminated water can be pasteurized at temperatures well below boiling. Contaminated water can be pasteurized in a black metal container in a simple solar cooker or reflector. As water heats in a solar cooker, temperatures of 56° C and above start killing disease-causing microbes. Heating water to 65° C (149° F) for 6 minutes, or to a higher temperature for a shorter time, will kill all disease causing microbes. (SCI, 2003)

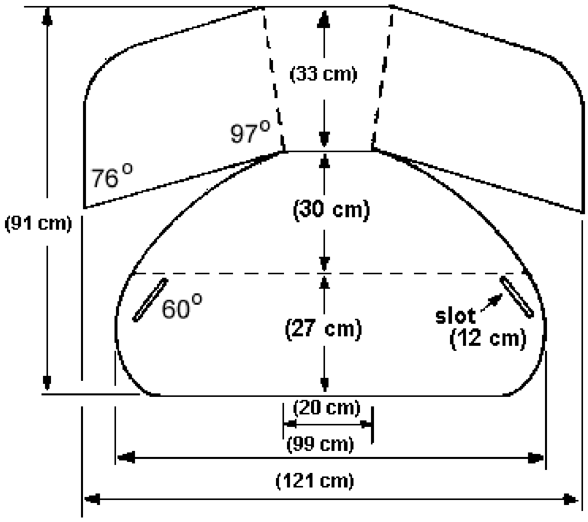


**Figure D.6. Cardboard dimensions for reflector**

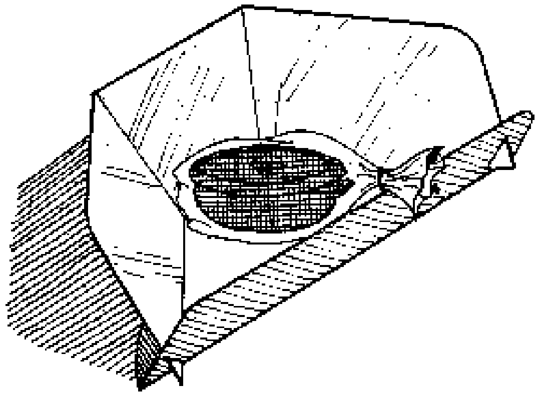


**Figure D.7. Keep reflector facing sun** (SCI, 2003)

This is how to construct the solar reflector:

a) Start with a big piece of cardboard about 1m x 1.33m.

b) Cut and fold as shown. The angles and folds shown are best, but small variations are OK. Hints: To make clean straight folds in cardboard, first make a crease along the line with a blunt edge such as a spoon handle, then fold against a firm straight edge. Make the slots a little too small and narrow so that they fit snugly to hold up the front panel.

c) Glue aluminium foil (or potato chip bags with silver coating) on the side that will form the inside surfaces when the oven is set up for cooking. Use wheat paste, glue, or tape to adhere to cardboard.

d) To set up, lay panel flat with shiny side up. Fold up front and back parts and fit back corners into the slots in front.

e) You're ready to cook! Place black pot on reflector and place in sun. Keep pot shadow centred on back of solar panel. It is possible to coat the pot black with carbon from a candle or wood fire. Raising the pot about 10 cm on a wire frame (or three stones), and covering with a clear oven cooking bag or salad bowl improves cooking speed.

## D.3. SODIS

SODIS uses solar energy to inactivate and destroy pathogenic micro–organisms; a combination of heat, oxidation, and ultraviolet (UV-A) radiation from the sun. This is the SODIS preparation and treatment process:
a) If the water is very turbid, let the particles settle and filter through a fine cloth.
b) fill bottle to three quarters, shake thoroughly 20 times, then fill completely. Filling to top avoids any air pockets reflecting sunlight. This is to facilitate oxidation and expose oxygen-saturated water to sunlight, as efficiency of disinfection is much increased by reactive forms of oxygen. (SODIS, 2002)
c) place on a black or reflective resting surface, with the clear side facing the sun. The CGI sheet and bottles are placed on a raised platform or existing roof surface away from animals.
d) The bottles are then laid horizontally (better exposure area) in direct sunlight for 6 hours from 9 am to 3pm (or for 2 days if 100% cloudy). Sheltered from wind is best. (WHO, 2005)
e) The water should be consumed directly from the bottle or transferred in a clean glass for drinking. It is very important to avoid recontamination.
f) Maintenance involves keeping the bottle clean, and care so that the transparent side does not get too scratched. (Burgess, 2002) The UV-A transmittance is very important for the efficiency of SODIS.

**Figure D.8. SODIS Procedure** (SANDEC, 2002)

*Simple Water Turbidity Test*:
To decide whether the water needs filtering, place the filled bottle on the SODIS Logo (see Figure to right, with letter size of about 1.5cm high) on top look through the bottle from top to bottom. If you can read the letters through the water, water turbidity is less than 30 NTU. If you can still see the sun rays of the Logo, turbidity is less than 20 NTU. If one cannot read the letters, the turbidity is more than 30 NTU, and needs pre-filtering or flocculation/ sedimentation using crushed Moringa oleifera seed. (SANDEC, 2002)

SODIS

## D.4. Moringa Treatment and Other Uses

The treatment process for 20 litres of moderately turbid water:
a) Matured seeds are removed from the pods, and shelled (most effective shelled). Seed solutions may be prepared from either seed kernels or the solid residue (presscake) obtained following extraction of seed oil. (Folkard et al, 2000)
b) Seed kernels are crushed (presscake ground to a fine powder) with a stone or mortar.
c) 2 grams (10 seeds) of powder is mixed with a cup of clean water to form a concentrated solution. A half full 0.5 L bottle works well. Shake for five minutes to activate compounds.
d) Filter out insoluble material using either a fine mesh screen or muslin cloth.
e) The milky white concentrated solution is added to 20 L turbid water.
f) Stir quickly for 30 seconds, then slowly and regularly (15 - 20 rotations per min) for 5 min.
g) After stirring the treated water should be covered and left to settle for at least one hour. If moved or shaken before then, clarification will take much longer or fail to reach completion.
h) Treated water should be siphoned or poured off the top, filtered through a clean cloth, into a second clean container.

The process just described assumes a final dosage of 100 mg/l, and uses a concentrated solution of about 0.8% w/v (2g powder in 250 ml). Depending on the turbidity of source water, dosages can be adjusted according to Table D.3. Ready-to-use coagulant solution can be prepared in varying concentrations of 0.5 to 5% w/v.

Solution containers should be cleaned between batches to remove insoluble seed material and fresh solution should be prepared every 8 hours. For practical reasons of solution preparation, the use of powdered seed kernels is only recommended for treatment systems up to 10m$^3$ / hour. (Folkard et al, 2000)

**Table D.3. Moringa dosage (unpurified powder)**

| Raw water turbidity (NTU) | Dose range (mg/l) |
|---|---|
| <50 | 10 - 50 |
| 50 - 150 | 30 - 100 |
| >150 | 50 - 200 |

Source: Folkard et al, 2000

The above table D.3 gives a rough guide to determine the dose requirement. Dosages are given as equivalent weight of seed powder or presscake material required to make up the dosing solution (crude extract, not purified active proteins).

**Table D.4. Products, Properties and Uses of the Moringa oleifera tree**

| | |
|---|---|
| Seed | • crushed whole seed or presscake remaining after oil extraction as a bio-coagulant for water and wastewater treatment<br>• seed bark and husks can be pyrolyzed to produce activated carbon |
| Vegetable (high nutrition value) | • an excellent source of Vitamins C, E, A, $B_1$, iron, calcium, and magnesium; very high in protein (22.9%) with 7 essential amino acids, phosphorus, and potassium.<br>• green pods as fresh or canned, common in Asian dishes<br>• young leaves are used as a vegetable in Africa<br>• dried leaves used as a highly nutritional supplement in porridges |
| Oil (seeds contain 35 -40% oil by weight) | • high quality edible oil comparable to olive oil.<br>• high in oleic acid – good for cooking and soap manufacture, as well as a anti-oxidizing cosmetics base, lubricant, and lamp fuel |
| Medicine | • all plant parts used as constituents in traditional medicines<br>• powered seeds are used to heal bacterial skin infection |
| Nutritional animal feed supplement | • the residual fibres obtained after oil and protein extractions for biotechnology applications, can be used as cattle feed-stock. |
| Erosion protection | • grown as live fences and wind breaks<br>• erosion protection with quick growth and tubular root structure. |
| Wood | • wood fuel source - tree tolerates cutting and regenerates well.<br>• pulp may be used in paper production |
| Other uses | • dye, gum, honey clarifying, beehive tree |

Sources: Sutherland et al (1994), Schwarz (2000), Sena et al (1998), and Fuglie (1999)

* Dried leafs are used as a powder supplement in a porridge for malnutritioned children in Orongo village, with convincing health benefit.

Recommended ecological parameters as a cash crop:

- Altitude: 10-1200m (sub-tropical climates). Highest altitude giving economic production is 1500m.
- Rainfall: ideally at least 500 mm /year, but can survive 250–1500mm depending on drainage. Drought tolerant. Needs sufficient moisture at planting. Does not support water logging.
- Temperature: 22-35C, max 48C. Below 20C it grows slowly and may affect seed production. Not tolerant to freezing.
- Soil: Alluvial sandy-loamy or sandy-clay; preferable slightly acid. Does not grow well on dry hill slopes with shallow soil.

Moringa oleifera can be easily established by cutting or by seed. Seeds can be sown either directly or in containers and no seed treatment is required. The tree grows extremely rapidly. Seedlings can achieve 2 metres in height within 12 months of planting, with flowers and fruit obtained within this first year. After 2 years the trees mature to 6 metre tall specimens. In some areas of southern India two harvests of seedpods are possible in a single year. Unchecked, the tree can grow up to 10m high. Read “The Miracle Tree” (Fuglie, 1999) for an extensive description of cultivation techniques, uses, and nutritional benefits.

## D.5. Chlorine Treatment – SWS

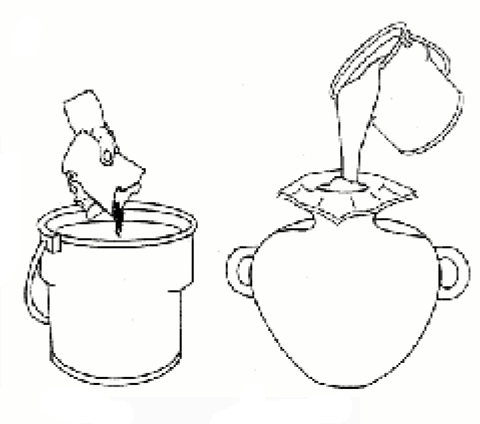
The chlorination preparation and treatment process:
a) turbid water requires pre-treatment. This can be settling for 12 hours, then filtering through two folds of clean white cotton or polyester cloth. Maximum turbidity = 5 NTU and pH < 8.0
b) Dosage table (1% sodium hypochlorite solution)

| Water Source | Plastic (20 litres) | Clay Pot (20 litres) |
|---|---|---|
| Clear (well, borehole, rain, lake) | 8 ml (1 capful) | 16 ml (2 capfuls) |
| Turbid (pond, river, stream) | 16 ml (2 capfuls) | 24 ml (3 capfuls) |

Source: CARE Kenya, 2003

c) shake or stir with a clean cooking stick for 30 seconds. Cover immediately and wait 1 hour before use. Keeping the vessel covered improves treatment.
d) to protect against re-contamination, residual chlorine of at least 0.5mg / l after 30 minutes contact time in water should be calculated for. However achieving this varies with type of water supply and local conditions. Where there is a risk of cholera or an outbreak has occurred, chlorine residuals of 1.0 mg/l should be maintained at wells.
e) Household chlorination must be supported by health, hygiene education, and risk reduction. (WHO, 2004 e)

## D.6. PuR Treatment



Adapted from P&G, 2004

PuR preparation and treatment process:
a) Add 1 sachet to 10 litres of water and stir to begin process of precipitation and coagulation
b) Stir water for 5 minutes until clear
c) Filter water through a clean cotton cloth and dispose of separated floc in latrine
d) Let clear water stand for 20 minutes to allow for complete disinfection
e) Store in a suitable container to prevent recontamination

**Picture D.1. The PuR process in five steps** (P&G, 2004)

# E. Treatment Method Comparison Summary

**Table E.1. Performance Comparison of Household Water Treatment Methods**

| **Criterion** | **SODIS UV + Heat** | **Solar (heat only) pasteurization** | **M. oleifera bio-coagulation** | **Chlorination and SWS** | **Combined chemical -PuR** |
|---|---|---|---|---|---|
| *Microbial Reductions* | Yes extensive, most pathogens | Yes extensive, most pathogens | Moderate | Yes extensive, most pathogens | Yes, extensive |
| *Diarrhoeal Disease Reductions* | Yes, 9-26%; two studies | None reported from studies, expected due to high temp 55+C) | None reported but expected, germicidal, turbidity reduc | Yes, 15-48%; many studies | Under study, expected due to multiple treatments |
| *Disinfectant Residual* | No | No | No? | Yes | Yes |
| *Quality Requirements of Water to be Treated* | Low turbidity (<30 NTU) for effective use; pre-treat turbid water | None | None;<br>OK with poor quality source water | Low turbidity (<30 NTU) & low cl demand; pre-treat turbid water | None; applicable to poor quality source water |
| *Chemical changes in water* | None or not significant | None or not significant | None or not significant | Yes; may cause taste, odour, disinfection by-products | Yes, may cause taste, odour, disinfection by-products |
| *Microbial regrowth potential in treated water* | Yes, with Storage beyond 1-2 days | Yes, with storage beyond 1-2 days | Yes, with Storage beyond 1 day | None to low if chlorine residual maintained | None to low if chlorine residual maintained |
| *Skill level and ease of Use* | Low skill; very easy use | Low skill; easy use with training | Moderate skill, Training in dosing and filtering | Low skill; easy use with training | Moderate, training in adding chem, mix, decanting and filtering |
| *Availability of Needed Materials* | Requires plastic (PET) bottles, dark or reflective roof surface | Requires black bottles of cook vessels and a solar reflector or solar cooker | Source of seeds | Requires source of free chlorine and source of safe storage vessels | Requires a source chem mixture (coagulants and cl); may limit availability |
| *Limits to Water Volume Treated* | Yes, treats 1-2 L per bottle; can simultaneously treat multiple bottles | Yes, treats 3-10 L per container; treat multiple vessels with multiple solar reflectors | No, easily scaled up | No, easily scaled up | Yes, chemical One packet treats fixed volumes 10 L; Cab scale up |
| *Performance verification requirements* | Measure that target temp is reached (thermometer or wax indicator) | Measure that target temp is reached (thermometer or wax indicator) | | Measure cl Residual, microbial (FC) quality indicator or both | Measure turbidity reduction, Measure cl residual |

## F. Kenya Statistics

**Table F.1. Statistics on Water, Sanitation, Lighting, and Fuel**

Sources of Water (% of households)

| | River / lake | Well / borehole | Spring | Piped | Pond / dam | Other (tank, etc) |
|---|---|---|---|---|---|---|
| Kenya | 35 | 14 | 13 | 13 | 7 | 3 (15?) |
| Rural Kenya | 36 | 25 | 15 | 15 | 6 | 3 |
| Nyanza Province | 40 | 17 | 24 | 9 | 7 | 3 |
| Kisumu town | 3 | 20 | | 58 | 1 | 18 |

Human Waste Disposal (% of households)

| | Main sewer | Pit latrine | Septic tank | Bush | Other |
|---|---|---|---|---|---|
| Kenya | 7.7 | 72.1 | 2.8 | 16.4 | 1 |
| Urban Kenya | 27.4 | 60.5 | 8.4 | 2.1 | 1.6 |
| Rural Kenya | 1 | 76.1 | 0.9 | 21.3 | 0.7 |
| Nyanza Province | 2.4 | 77 | 0.9 | 18.5 | 1.2 |
| Kisumu Town | 16.2 | 76.3 | 2.7 | 12.2 | 1.2 |

Main Lighting (% of households)

| | Electricity | Paraffin lamp | Solar | Other |
|---|---|---|---|---|
| Kenya | 13.6 | 79.1 | 0.5 | 6.8 |
| Urban Kenya | 42.1 | 55.3 | 0.5 | 2.1 |
| Rural Kenya | 4.2 | 87 | 0.5 | 8.3 |
| Nyanza Province | 4.8 | 92.5 | 0.3 | 2.4 |
| Kisumu Town | 26.7 | 70.7 | 0.2 | 2.4 |

Cooking Fuels (% of households)

| | Firewood | Paraffin | Charcoal | Electricity | Gas | Solar |
|---|---|---|---|---|---|---|
| Kenya | 68.8 | 17.2 | 9.7 | 1.5 | 2.4 | 0.3 |
| Rural Kenya | 88.4 | 4.2 | 6.0 | > 0.5 | > 0.5 | > 0.5 |
| Nyanza Province | 81.6 | 5.7 | 10.5 | 0.9 | 0.6 | 0.4 |
| Kisumu Town | 51.4 | 20.9 | 23.2 | 1.5 | 2.3 | 0.2 |

Distribution of Roofing Materials (% of households)

| | Iron Sheet | Grass / makuti | Tile / concrete | Asbestos | Other |
|---|---|---|---|---|---|
| Kenya | 63.9 | 27.9 | 4.5 | 1.3 | 2.4 |
| Kisumu Town | 87.3 | 0.5 | 6.3 | 5.2 | 0.7 |

Source: (CBS, 2002)

## G. Organizations and Contacts

Each of the following organizations and people were of kind assistance with information.

▪ *Engineers Without Borders (EWB) Sweden* is a non-profit NGO with the mission to contribute to sustainable global development by sharing technological and scientific knowledge with disadvantaged communities. EWB Sweden selected Orongo village to try establish a pilot sustainable technology and knowledge centre project. www.inug.nu
▪ *Intermediate Technology Development Group (ITDG)*. Promoting environmental conservation and appropriate technology. Kisumu office: itkisumu@africaonline.co.ke; itdgEA@itdg.or.ke; www.itdg.org
▪ *Kenya Marine & Fisheries Research Institute (KMFRI)*. Lake conservation and management with lab facilities to support water analysis research and monitoring. Dr. Richard Abila (Assistant Director) www.kmfri.org
▪ *Kisumu District Development Office*. Census / planning reports. Evans Gichana (Librarian)
▪ *Kisumu Municipal Council Environment Department*. Environmental management and planning, EIA, environmental regulation. George Wasonga (Director); Ben Obura (Deputy Director); Thomas Ouru Swetta
▪ *Lake Basin Devlpmt Authority (LBDA)*. Water and land management, planning for the Lake Victoria Basin. William Ogola (agronomist); Joseph Okotto-Okotto (Senior Cartographer)
▪ *Lake Victoria Environment Monitoring Program (LVEMP)* has active programs of wetlands management, catchment afforestation, and integrated soil and water management. The main aim is managing the Lake ecosystem for sustainable utilisation of resources in order to enhance socio-economic development of the riparian communities, while reduction of sediment and nutrient flow into Lake Victoria. www.lvemp.org
▪ *Lake Victoria School Cooperation (LAVISCA)* is a Kenya-based organization working to spread sustainable knowledge through community integrated teaching and cooperation between schools in Scandinavia and the Lake Victoria region. Stevens Ahoya (Secretary);
Dr. Phoebe Nyawalo (Coordinator Kenya and Sweden)
▪ *Ministry of Water Resources Mgmt Dept (Nyanza Province)*. Based in Kisumu, have pollution experts (Mr. Okungu), hydrogeologists (Stanley Acholla), and water chemists (Mr. Maturwe, Jackson Makokle). Have a laboratory facility to do chemical analysis, and in cooperation with the Government Chemists Department, (Boniface Achuma and Sheundah Ndakalu) do microbiological testing.
▪ *Moringa Research and Promotion Project* at the Farmer's Training Centre in Homa Bay. Michael Ongonga works tirelessly sharing the knowledge of Moringa throughout the region and has seeds available for purchase. Email: ongongamoringa@racham.westernet.co.ke
▪ *NGO Network for Western Kenya* are coordinating NGO efforts and have contact information about the organisations operating in the Kenyan Lake Victoria region. Betty Okero or Chris Owalla; email: ngonet_west@yahoo.com
▪ *Orongo Widows and Orphans Group*. Supporting HIV/AIDS widows and orphans, promoting awareness, natural health, water safety, and growing Moringa. Florence Gundo; email: orongowidows@yahoo.com
▪ *Sustainable Aid in Africa International (SANA)* is an NGO based in Kisumu, working with water and sanitation in Nyanza Province. They have roof catchment, spring protection, and Ecosan latrine projects. Alfred Adongo (CEO); Rosemary Moi (community operations). www.sanainternational.20m.com; email: sana@swiftkisumu.com
▪ *Society for Women with AIDS in Kenya (SWAK)*, with an office in Kisumu, is a partner with CARE in the Nyanza Healthy Water Project to implement the Safe Water System.