University of Nairobi
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Computer Code for Selecting Appropriate Point of Use Water Filtration Treatment Technology

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A thesis submitted in partial fulfillment for the Degree of Master of Science in Environmental Engineering in the Department of Environmental and Biosystems Engineering in the University of Nairobi

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Declaration

I ORINA EDWIN AKUNGA declare that this thesis is my original work and to the best of my knowledge it has not been submitted in any other university for examination.

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Edwin A. Orina Date

This thesis has been submitted for examination with our approval as university supervisors

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Dr. Christian Omuto Date

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Prof. Elijah K. Biamah Date

Dedication

To the families of North Eastern Kenyan people who die in numbers as a result of water related ailments. “God will wipe away your tears”.

Acknowledgement

To God, for giving me the strength and opportunity to pursue my dreams.

To Dad, Late mother and my siblings for your unmatched love. Life has never been easy.

To Dr. Christian Omuto, for his boundless energy and knowledge. The world is a much better place with people like you in it.

To Prof. Elijah Biamah, for constant encouragement and guidance. Surely your wisdom and insight of life is second to none.

To the staff and students of Environmental and Biosystems engineering, for being the most phenomenal group of people I’ve ever had a pleasure of meeting. Knowing all of you was a rewarding educational experience in itself.

To the families and victims of post election violence, for not giving up in this life. Vengeance belongs to the Lord.

To the republic of Kenya my home, my pride.

Abstract

Water is fundamental for human health and survival. Adequate water availability and quality are key components to alleviating poverty in developing nations. Unfortunately, the right to safe water is not recognized for a large portion of the world's poorest citizens as at least 1.1 billion people lack access to water and 2.6 billion people lack adequate sanitation (WHO/UNICEF JMP, 2000). This has been identified as "a silent humanitarian crisis that each day takes thousands of lives, robs the poor of their health, thwarts progress toward gender equality, and hamstrings economic development, particularly in Africa and Asia (United Nations Millennium Project, 2005)".

Provision of safe water in developing nations is often times hindered by lack of funds required for installation of conventional treatment utilities coupled with inadequate technical capabilities required for their operation and maintenance. Thus new alternative strategies are urgently needed to address the world's current water crisis especially in third world countries. One such alternative is the promotion and implementation of Household Water Treatment and Safe Storage (HWTS) technologies.

Program implementation organization survey and a HWTS technology selection tool to aid in the implementation of household water treatment and safe storage systems for local communities in developing nations has been developed. It focuses more on the social-economic aspects of the implementation process. The information it provides in comparing performance is ad hoc and subjective. This thesis has developed the Household Filtration Treatment (HFT) Evaluation System™ solution through code developed in using the C# (sharp) programming language.

C# combines the power and efficiency of C++, the simple and clean Object Oriented design of Java and the language simplification of Visual Basic.

Coupled with its provision for garbage memory collection at runtime, type and memory access checking, new and exciting features such as reflections, attributes, marshalling, remoting, threads, streams, data access with ADO.Net no doubt made it the best programming language for this application.

Thesis objective to develop a program which compares the performance of different household water treatment and safe storage technologies was met. The program compares filters within the same technology and for different technologies. Such a feature is advantageous in the sense that not only can the best technology be selected but also general trends are easily established within specific household filtration technologies. For instance, comparisons between biosand filter and ceramic filter show that the later is best in faecal contamination reduction while the former gives the highest rates of filter flow though; both achieve permissible turbidity considered fit for human drinking.

It is hoped that water and sanitation actors including NonGovernmental Organizations, different Governmental departments , United Nation Children Education Fund and others will find HFT Evaluation System™ important in propagating household water treatment and safe storage technologies towards achievement of environmental sustainability millennium development goal and in particular "halve, by 2015, the proportion of the world without sustainable access to safe drinking water and basic sanitation".

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Acronyms and Abbreviations

AAH	Action Against Hunger
ACF,	Action Contra Faim
BSF	Biosand Filter
CARE	Cooperative for Assistance and Relief Everywhere
CAWST	Centre for Affordable Water and Sanitation Technology
CDC	Centers for Disease Control and Prevention
C Sharp	Programming language
FC	Faecal count
HFT	Household Filtration Treatment
HWTS	Household Water Treatment and Safe Storage
JMP	Joint Monitoring Programme
MDG	Millennium Development Goal
MIT	Massachusetts Institute of Technology
NGO	Non-government organization
NTU	Nephelometric turbidity units
PFP	Potters for Peace
PVC	Polyvinyl chloride
STI	Science, Technology and Innovation
UN	United Nations
UNEP	United Nation’s Environmental Programme
UNICEF	United Nations International Children's Emergency Fund
U.S	United States
WHO	World Health Organization
CLR	Common Language Runtime
IL	Intermediate Language.
XML	Extensible Markup Language,
GUI	Graphics User Interface
OOP	Object Oriented Programming
DLL	Dynamically Linked Library

Introduction

1.1. Background

In September of 2000, the United Nations issued a set of "Millennium Development Goals[1]" (MDGs) meant to address the most pressing issues faced by the world at that point in time. Of these goals, the seventh specifically addressed the issue of environmental sustainability and in doing so set as a target to "halve, by 2015, the proportion of the world without sustainable access to safe drinking water and basic sanitation".

Although the MDGs were formulated in 2000, the baseline for most of the MDG targets, including those for water and sanitation, has been set at 1990. Subsequently, 2002 is considered the halfway mark towards achieving the 2015 MDG deadline. Consequently, a mid-term assessment report was produced jointly by World Health Organization (WHO) and United Nations International Children's Emergency Fund (UNICEF), providing coverage data for 1990 and 2002 at national, regional and global levels and an analysis of trends towards 2015 (WHO/UNICEF JMP, 2004).

In regard to the worldwide drinking water target, the mid-term assessment report prognosis a relatively accurate one. The report indicated a remarkable progress from 1990 to 2002, where the proportion of people with access to improved drinking water sources[2] increasing from 77 to 83 percent. This accounts for a total of 1.1 billion people benefiting from increasingly safe and sanitary drinking water sources. Although these numbers project that the Millennium Development Goal will be met on a global level, it is tempered by the fact that certain regions of the world are still struggling to provide improved drinking water sources to currently unserved population. One such

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[1] The Millennium Development Goals are blueprints agreed to by the member states of the United Nations and the world's leading development institutions, (September 2000).

[2] An improved drinking-water source is defined as one that, by nature of its construction or through active intervention, is protected from outside contamination, in particular from contamination with faecal matter.
(WHO / UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation)

region is sub-Saharan Africa which, despite having an increase in coverage from 49 to 58 percent, is still projected to fall short of reaching the Millennium Development Goal of 75 percent coverage by 2015. Factors cited as contributing to the impeded progress in the region are population growth, political instability, and low priority given to water and sanitation. One solution proposed for this region is the "decentralization of responsibility and ownership providing a choice of service level to communities, based on their ability and willingness to pay". (WHO/UNICEF JMP, 2004)

Providing more than half a billion people with safe drinking water is a major task, especially because most of them are living in rural areas. Despite major efforts to deliver safe, piped, community water to the world's population, the reality is that water supplies delivering safe water will not be available to these people on such a short term. According to the WHO a short-term solution to meet the basic need of safe drinking water can be found in household water treatment and safe storage (HWTS).

According to the report, Kenya experienced a 38 percent increase in water coverage during this period, indicating that the country was well on its way to achieving the MDG target. However, aggregate trends in Africa's progress toward the MDGs mask high levels of spatial and group disparities in performance. In particular, progress on all indicators is skewed in favor of high-income groups and urban populations. The inequities in access to public services such as health, water and sanitation result in the further marginalization of excluded groups.

Addressing the concern of safe drinking water requires that population growth also be taken into account. The report indicates that despite a tremendous number of people gaining access to improved drinking water sources per year, reported at 90 million, an average population growth of 80 million people per year only results in a net total increase of 10 million per year. The report also cites a tremendous discrepancy in the proportion of populations being served between urban and rural areas of developing nations. In sub-Saharan Africa, for instance, the disparity between populations in urban and rural areas is reported at 37 percent. This indicates that a greater focus on rural areas in developing nations is needed to be able to attain the 2015 target. (WHO/UNICEF JMP, 2004).

This state of affairs was acknowledged in the 2010 High Level Meeting on the Millennium Development Goals' (MDGs) Outcome Document, which proposed tackling inequalities as an important way to scale-up progress for all segments of the population. The document proposes specific interventions, such as Social protection programs, low echelon technological projects among others to create a level playing field for all, to ensure the availability, continuity, and access to public services, and to accelerate progress toward the MDGs. (Assessing Progress in Africa toward the Millennium Development Goals, MDG Report 2011).

Kenya enacted a new constitution in August 2010, whoseforth chapter is dedicated to the bill of rights which is an integral part of the country's democratic state and is the framework for social, economic and cultural policies. The bill stipulates that these rights and freedoms belong to each individual and are not granted by the state. This is so to preserve the dignity of individuals and communities thus promoting social justice and the realization of the potential of all human beings. Article 43(d) clearly states that "Every person has the right— to clean and safe water in adequate quantities;" (The Constitution of Kenya, 2010).

Further, Kenya's vision 2030 which is the government blue print for transforming the country into a middle income nation providing a high quality of life to its citizens by 2030 identifies the economic, the social and the political pillars as strategies to achieving this vision. The economic pillar seeks to achieve a gross Domestic Product of 10% per annum starting the year

2012 while the political pillar aims to realize a democratic political system where the rights and freedoms of all individuals are not only respected but also protected. Alternatively, it is the social pillar which indeed assures of a just country where all citizenry has equitable opportunities to development in a clean and secure environment.

This quest is the basis of transformation of our society in seven key social sectors: Education and Training; Health; Water and Sanitation; the Environment; Housing and Urbanization; as well as in Gender, Youth, Sports and Culture, Equity and Poverty Eradication. In making special provisions for Kenyans with various disabilities and previously marginalized communities, vision 2030 singles out the fact that pushing these policies will require an all round adoption of science, technology and innovation (STI) as an implementation tool.

Kenya is a water scarce country. The economic and social developments anticipated by Vision 2030 will require more high quality water supplies than at present. The country, therefore, aims to conserve water sources and start new ways of harvesting and using rain and underground water. The 2030 vision for water and sanitation is to ensure that improved water and sanitation are available and accessible to all. The goal for 2012 is to increase both access to safe water and sanitation in both rural and urban areas beyond present levels. (Kenya Vision 2030, Popular Version)

For successful attainment of its objectives vision 2030 silently subsumes achievement of millennium development goals by 2015. However, it is now even more apparent that the later may not be reached including the water targets enshrined in environmental sustainability goal. A close analysis of the flagship projects highlighted for implementation indicates that although water and sanitation goal above describes water quality, there are no specific projects geared towards achieving it. Since proposed projects seek to increase available water quantities. Indeed water quality is a critical concern not only for local or regional populations but a global worry which requires concerted efforts in providing appropriate solutions.

Microbial contamination of drinking water sources is a problem affecting many developing nations around the world. The use of polluted water for drinking and bathing is a principal pathway for infection by diseases that kill millions and sicken more than a billion people each year (World Bank, 1992). Unsafe water is implicated in many cases of diarrheal disease. Approximately four billion cases of diarrhea each year cause 2.2 million deaths, mostly among children under the age of five. The most widespread contamination of water is from disease-bearing human and animal wastes, typically detected by measuring fecal coliform levels. Human wastes pose great health risks for the many people who are compelled to drink and wash in untreated water from rivers and other surface water sources (World Bank, 1992).

In industrialized societies, the provision of safe water has typically been accomplished through the use of community-wide systems such as centralized water treatment plants and piped distribution networks. Unfortunately, the installation of these utilities is often times not cost-effective in developing nations. Funds are typically not available, nor are the technical capabilities required for operation and maintenance. New alternative strategies are urgently needed to address the world's current water crisis. One such alternative is the promotion and implementation of household water treatment and safe storage (HWTS) technologies. Household systems give an immediate and sustainable solution to the provision of safe water at the lowest level possible.

There is now conclusive evidence that simple, acceptable, low-cost interventions at the household and community level are capable of dramatically improving the microbial quality of household water and reducing the risks of diarrheal disease and death in populations of all ages in the developed and developing world (Sobsey, 2002).

There is a growing body of literature and research available on most of the individual HWTS technologies. One important report is by Mark Sobsey (2002) for the World Health Organization's Water, Sanitation and Health Programme. The report, entitled "Managing Water in the Home: Accelerated Health Gains from Improved Water Supply", attempts to describe and review each of the various available HWTS systems. The report provides a scientifically sound and supportable basis for identifying, accepting, and promoting HWTS technologies so that programs in support of the implementation of household water treatment and storage can be developed and disseminated elsewhere (Sobsey, 2002).

In Sobsey's 2002, over-population, urban-growth and expansion, peri-urban settlement, deforestation, global change, and increased coverage of the earth's surface with impervious materials are cited as specific factors that are increasing the potential of fecal contamination of drinking water sources. The document further indicates that the current global numbers reported for populations lacking access to safe drinking water are conservative, and that the actual situation is much worse than described. This is due to several simplifying assumptions made in regard to distribution, transport, and practices at the household level.

The author argues that even with "effective" distribution systems, there is still a large potential for contamination in distribution systems due to inadequate maintenance, in addition to the potential of contamination at "protected" sources. Furthermore, practices during transport and storage of water at individual homes are not accounted for. These practices may not adequately protect water from contamination at this level. The author argues that education regarding hygienic practices during transport and at the home is necessary to protect water sources at the household level, (Sobsey, 2002)

There is currently a proactive approach aimed at implementing HWTS technologies throughout the globe both by local governments and non-government organizations (NGOs) such as the Centre for Affordable Water and Sanitation Technology (CAWST), CARE, Action Against Hunger and Potters for Peace. In addition to this, there is also a tremendous involvement on the part of international aid organizations such as MEDAIR and the UNICEF. Also among these organizations is the World Health Organization, which is actively attempting to "accelerate health gains to those without reliable access to safe drinking water" through the promotion of HWTS technologies. (WHO, 2005).

Evaluation of the most appropriate technology has not been effected, a factor attributed to the ad hoc nature of manual systems used in comparisons hence resulting in subjective conclusions. This study will endeavor to remove such drudgeries by development of an automated evaluation platform.

1.2. Research Problem Statement

Water is fundamental for human health and survival. Adequate water availability and quality are key components to alleviating poverty in developing nations. Unfortunately, the right to safe water is not recognized for a large portion of the world's poorest citizens as at least 1.1 billion people lack access to water and 2.6 billion people lack adequate sanitation (WHO/UNICEF JMP, 2000). This has been identified as "a silent humanitarian crisis that each day takes thousands of lives, robs the poor of their health, thwarts progress toward gender equality, and hamstrings economic development, particularly in Africa and Asia (United Nations Millennium Project, 2005)".

Provision of safe water in developing nations is often times hindered by among others lack of funds required for installation of conventional treatment utilities coupled with inadequate technical capabilities required for their operation and maintenance. The situation is further exacerbated in rural areas by the fact that populations are spread through expansive spatial areas hence requiring huge investments capital to lay conventional water infrastructure. Thus new alternative strategies are urgently needed to address the world's current water crisis especially in third world countries. One such alternative is the promotion and implementation of Household Water Treatment and Safe Storage (HWTS) technologies.

Program implementation organization survey and a HWTS technology selection tool to aid in the implementation of household water treatment and safe storage systems for local communities in developing nations has been developed. The implementation survey and technology selection tool takes into account though, to varying details all facets of program implementation and is designed with inherent flexibility in order to be used by local communities as well as global agencies, governments, organizations, and enterprises involved in program implementation.

However, this tool does not provide a lucid means through which the technical performance of these household treatment technologies is evaluated. It focuses more on the social-economic aspects of the implementation process. The information it provides in comparing performance is ad hoc and subjective. Often times this has led to failure of the chosen technology to address the intended needs, and as a result resources have been wasted due to non performance or total abandonment of such endeavors. This obstacle has slowed down the implementation of household water treatment and safe storage technologies and hence denying millions access to safe drinking water.

Therefore, there is a need to develop a tool which eliminates the ad hoc procedure in performance comparison while maintaining consistency in its results. This thesis endeavors to solve this problem through the development of computer code.

1.3. Justification

Access to safe water is a basic human right that has been denied to a large proportion of the world's population. Only 0.7% of the world's water supply is available for consumption and, unfortunately, it is disproportionately distributed. Over one half of the people living in developing countries suffer from diseases related to unsafe water supply and sanitation (WHO, 1996a). At the beginning of 2000 one-sixth (1.1 billion people) of the world's population was without access to improved water supply (UNICEF, 2002).

The majority of these people live in Asia and Africa, where fewer than one-half of all Asians have access to improved sanitation and two out of five Africans lack improved water supply. These figures are all the more shocking because they reflect the results of at least twenty years of concerted effort and publicity to improve coverage (WHO, 2000). More shocking is an assertion by UNEP which estimates that even if the world maintained the pace of 1990's water supply development it would not be enough to ensure safe access to drinking water for everyone by 2025.

Current estimates of the number of people using microbiologically unsafe water are probably low. This is because the assumptions about the safety or quality of water based on its source, extent of treatment or consumer handling do not take into consideration several well-documented problems. One problem is that so-called protected or improved sources, such as boreholes and treated urban supplies, can still be fecally contaminated and deliver microbially unsafe water. In some cities the water systems abstract unsafe water from unprotected or contaminated sources and deliver it to consumers with no or inadequate treatment, yet these water systems are classified or categorized as improved and safe.

Another problem contributing to the underestimation of the population served by unsafe water is contamination of water during distribution whether water is piped or carried into the home. Many communities have protected or improved water supplies and treated water that is microbiologically safe when collected or when it leaves a treatment plant.
However, substandard water distribution systems, intermittent water pressure due to power outages and other disruptions, and illegal connections to the distribution system often lead to the introduction of fecal contamination and therefore, microbiologically contaminated water at the consumer's tap or collection point (Sobsey, 2002).

In order to meet goals set out by the UN millennium project (in particular the aim of halving the proportion of people who suffer from hunger by 2015), it will be necessary to manage freshwater resources from the moment that rainwater hits the land surface. In addition, the state of human health is linked to a range of water-related conditions: safe drinking water, adequate sanitation, minimized burden of water related disease and healthy freshwater ecosystems. To meet the millennium development goals on health, urgent improvements in the ways in which water use and sanitation are managed are required.

There is currently a proactive approach aimed at implementing HWTS technologies throughout the globe both by local governments and non-government organizations (NGOs) such as the Centre for Affordable Water and Sanitation Technology (CAWST), CARE, Oxfam, Action Against Hunger and Potters for Peace. In addition to this, there is also a tremendous involvement on the part of international aid organizations such as MEDAIR and the UNICEF as well as national agencies like the Centers for Disease Control and Prevention (CDC).

Also among these organizations is the World Health Organization, which is actively attempting to "accelerate health gains to those without reliable access to safe drinking water" through the promotion of HWTS technologies. The WHO has established the International Network for the Promotion of Safe Household Water Treatment and Storage (The "Network"), in collaboration with the United Nations, bilateral agencies, private sector companies, NGOs, and research institutions such as MIT (WHO, 2005). The network format optimizes flexibility, participation and creativity to support coordinated action.

Local governments in developing nations are recognizing the efficacy of these technologies and have begun to include HWTS systems in policy considerations. For instance, the Government of Nepal, along with several local and global organizations involved with health and sanitation, has embarked upon programs aimed at addressing the treatment of both arsenic and microbially contaminated drinking water. The concept has been tried in Kenya for the past five years and slowly gaining acceptance mostly in arid and semi arid regions.

There are a wide range of HWTS technologies available that are relatively inexpensive and require little if any technical skill for operation and maintenance. Each technology has specific strengths and limitations in certain implementation scenarios. Technologies vary in cost, availability, and performance. This thesis has developed a tool through which the later parameter for different technologies can be compared in C#.

C# combines the power and efficiency of C++, the simple and clean Object Oriented design of Java and the language simplification of Visual Basic.

Coupled with its provision for garbage memory collection at runtime, type and memory access checking, new and exciting features such as reflections, attributes, marshalling, remoting, threads, streams, data access with ADO.Net formed the basis of its choice as the best programming language for this application.

1.4. Objectives

The main objective of the study was to develop a program which compares the performance of different household water treatment and safe storage technologies.

Specific objectives were,

1. To develop a computer code in C Sharp which evaluates the performance of Household Water Treatment and Safe Storage technologies based on flow rate, turbidity and faecal contamination
2. To use the code in (1) above to compare the performance of Biosand filter and Filtron (ceramic) filter.

Literature review

2.1 Water crisis

About 31 percent of Kenyans receive their drinking water from a pipe (household or communal tap); while 37 percent obtain water from an open spring, stream, or river. The rest obtain water from wells, water vendors or other sources (Central Bureau of Statistics, 2004). In 2002, it was estimated by the World Health Organization that 38 percent of Kenyans lacked access to safe drinking water with this number increasing to 54 percent in rural areas. Reportedly 31 percent of the population has to travel more than half an hour to fetch water (WHO, 2004).

Water scarcity is also an impending problem for the country. Droughts and inadequate rainfall have lead to a deficit in renewable freshwater resources. This scarcity has dire consequences to the health and financial well-being of the nation's people as a large portion of the economy is highly dependent on water-intensive livelihoods such as agriculture and livestock. Kenya is recognized by the United Nation's Environmental Programme (UNEP) as being a "water scarce" nation, meaning that average supplies of available freshwater per capita fall below 1,000 cubic meters per year. This is emphasized further in figure 2.1 which compares Kenya's freshwater availability to other world nations in the year 2000.

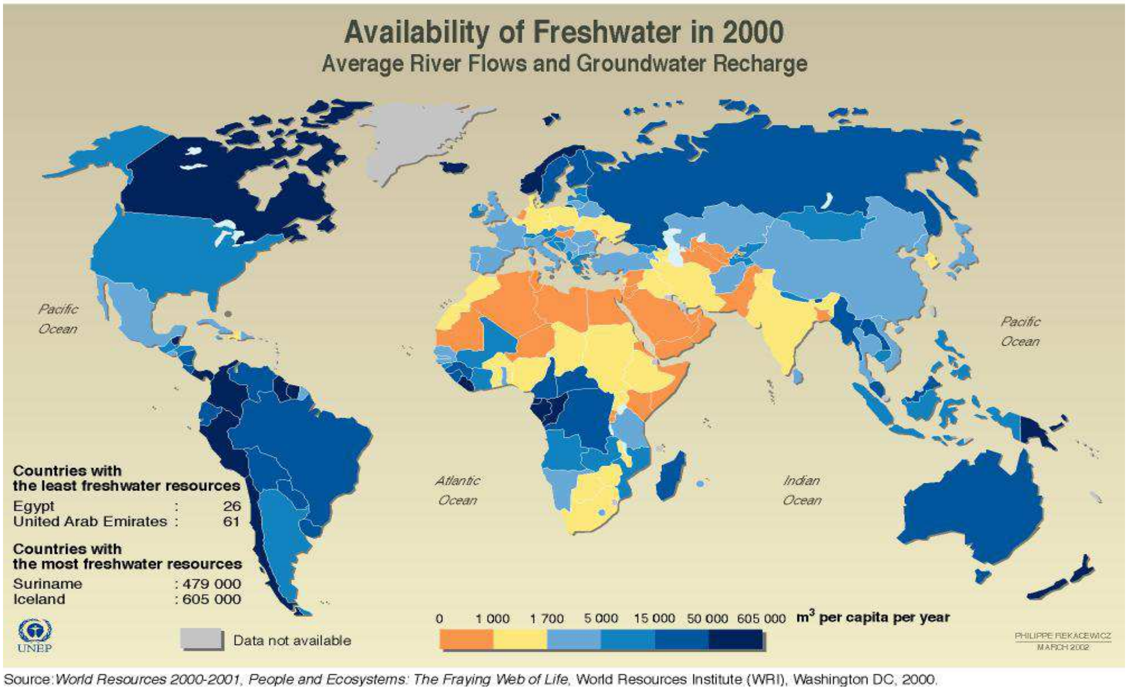

Figure 2.1: Availability of Freshwater in the world, Source: UNEP

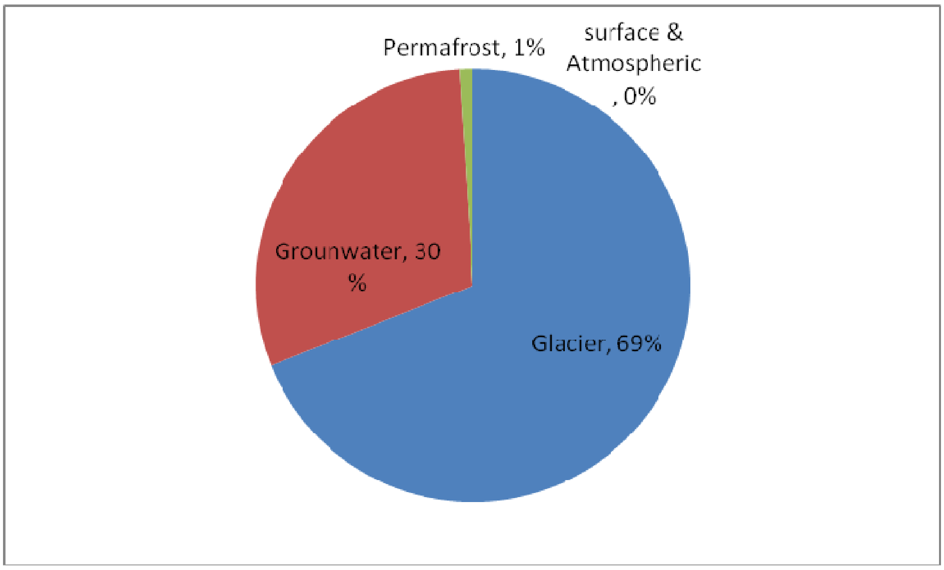

Figure 2.2: Distribution of worlds freshwater

Source: UNEOP; http://maps.grida.no/go/graphic/freshwater-availabilitygroundwater-and-river-flow

Figure 2.2 demonstrates that barely 1% of freshwater is theoretically available for agriculture, industry and human consumption. Furthermore, availability is uneven, and often not readily accessible.

Water is becoming scarcer and more polluted for example through human activities. In particular, microbial pollution of water remains the greatest single cause of illness and mortality, according to the UNICEF. A combination of unsafe water and poor sanitation is the world's second biggest killer of children, with about 1.8million children dying annually.

Water stress has a direct impact on water quality. In facing conditions of limited water supply, as alternative people normally acquire water from the most accessible and readily available sources. Unfortunately, these sources may be highly turbid and contaminated surface water sources. This leads to a higher probability of contracting diseases thus enforcing further the role of household water treatment.

Problems of water supply and quality are further exacerbated in rural versus urban areas. Approximately 90 percent of the urban population in Kenya has access to improved water sources, while only 45 percent of the rural population has access to improved water sources (UNICEF, 2002).

2.2. Household water treatment and safe storage (HWTS) technologies

To overcome the difficulties in providing safe water and sanitation to those that lack it, we need more research into novel interventions and effective implementation strategies that can increase the adoption of technologies and improve prospects for sustainability. Despite general support for water supply and sanitation, the most appropriate and effective interventions in developing countries are subject to significant debate. The weak links between the water, health, and financial sectors could be improved by communication programs emphasizing health[3] as well as micro- and macroeconomic benefits that could be gained by achieving the safe water goals.

The new focus on novel interventions has led researchers to re-evaluate the dominant paradigm that has guided water and sanitation activities since the 1980s. A literature review of 144 studies by Esrey et al. (1991) best summarized the old paradigm, concluding that sanitation and hygiene education yielded greater reductions in diarrheal disease (36 percent and 33 percent, respectively) than water supply or water quality interventions[4]. However, a more recent meta-analysis commissioned by the World Bank contradicted these findings, showing that hygiene education and water quality improvements were more effective at reducing the incidence of diarrheal disease (42 percent and 39 percent, respectively) than sanitation provision and water supply (24 percent and 23 percent, respectively) (Fewtrell & Colford, 2004).

The discrepancy between these findings can be attributed in part to a difference in intervention methodology. Esrey et al. (1991) reviewed studies that largely measured the impact of water quality improvements at the source (i.e., the wellhead or community tap). Since 1996, a large body of published work has examined the health impact of interventions that improve water quality at the point of use through household water treatment and safe storage (HWTS; Fewtrell & Colford, 2004). These recent studies, many of them randomized controlled intervention trials have highlighted the role of contamination of drinking water during collection, transport, and storage (Clasen & Bastable, 2003), and the health value of effective HWTS (Clasen et

[3] The health consequences of inadequate water and sanitation services include an estimated 4 billion cases of diarrhea and 2.2 million deaths each year, mostly among young children in developing countries (WHO/UNICEF, 2000). In addition, waterborne diarrheal diseases lead to decreased food intake and nutrient absorption, malnutrition, reduced resistance to infection (Baqui et al., 1993), and impaired physical growth and cognitive development (Guerrant et al., 1999).
[4] This study reinforced previous work (Esrey, 1985) that had influenced the water and sanitation sector to de-emphasize improving water quality as a way to reduce diarrheal disease incidence.

al., 2004; Quick et al., 1999, 2002; Conroy et al., 1999, 2001; Reller et al., 2003).

In 2003, as the evidence base for the health benefits of HWTS methods grew, institutions from academia, government, NGOs, and the private sector formed the International Network to Promote Household Water Treatment and Safe Storage, housed at the World Health Organization in Geneva, Switzerland. Its stated goal is “to contribute to a significant reduction in waterborne disease, especially among vulnerable populations, by promoting household water treatment and safe storage as a key component of water, sanitation, and hygiene programmes” (WHO, 2005).

Although the ultimate goal of any community should be achieving the highest level of water service possible, household systems give an immediate and sustainable solution to the provision of safe water at the household level.

Household water treatment acts on the principle that water can be contaminated at various stages prior to use. A pristine water source can become microbially contaminated by improper transport, storage, and use practices in the home. By treating water immediately before intended use, the possibility of contamination is significantly lessened. Household treatment is implemented in combination with safe storage, sanitation, and hygiene in order to achieve maximum benefits to the household. Safe storage refers to storing water in protected containers that restrict physical access prior to use.

In Mandera, most people – predominately women – spend a portion of their day collecting, carrying and storing water for drinking. The water that ends up in the house does not originate from a typical water treatment plant and supply system, but comes to them from a variety of sources including local dug wells, seasonal rivers (Laga), earth dams and pans. If the water is not already contaminated at the source, it often becomes contaminated at some point during transport and/or during handling storage before it is consumed.

A study commissioned by the WHO identified 37 different products, technologies and approaches that are used for the microbiological treatment of drinking water in the home (Sobsey 2002). Only a few of these approaches have been rigorously assessed for the microbiological performance and health impact. It is now acceptable that chlorination, filtration (biosand and ceramic/filtron), solar disinfection, combined filtration/chlorination, and combined flocculation/chlorination are the most common HWTS options.

This thesis focuses on point-of-use drinking water treatment and safe storage options, which can accelerate the health gains associated with improved water until the longer-term goal of universal access to piped, treated water is achieved.

Porous stones and a variety of other natural materials have been used to filter visible contaminants from water for hundreds of years. These mechanical filters are an attractive option for household treatment because: There are many locally available and inexpensive options for filtering water; They are simple and ease of use; and Such filter media are potentially long-lived. However, filtration is the least studied HWTS intervention, and pathogen removal, filter maintenance, and the lack of residual protection pose challenges in implementation.

A recent health impact study in Bolivia documented a 64 percent reduction in diarrhea in users of 0.2 micron ceramic candle-shaped filters manufactured in Switzerland (Clasen et al., 2004)[5]. Users prevented recontamination by using a tight-fitting lid over the receptacle, a tight seal to prevent leaking around the filters into the receptacle, and a spigot to access the water; in addition, users

[5] Most currently used filtration options are locally manufactured.

could clean the filters without removing them and thus exposing the water in the receptacle to potential contaminants.

2.3.Biosand filter

The Biosand Filter (BSF) is a water filtering technology that was modified from the traditional large-scale community slow sand filter to a small-scale filter for household use. The BSF was developed in 1988 by Dr. David Manz of the University of Calgary, Canada, in response to various issues that were brought to attention from various water treatment projects. The container is constructed from concrete formed in a mold. Gravel, followed by coarse sand and then fine graded quartz sand, are layered in the container as shown in fig 2.3 (Bruzunis, BJ. 1993.)

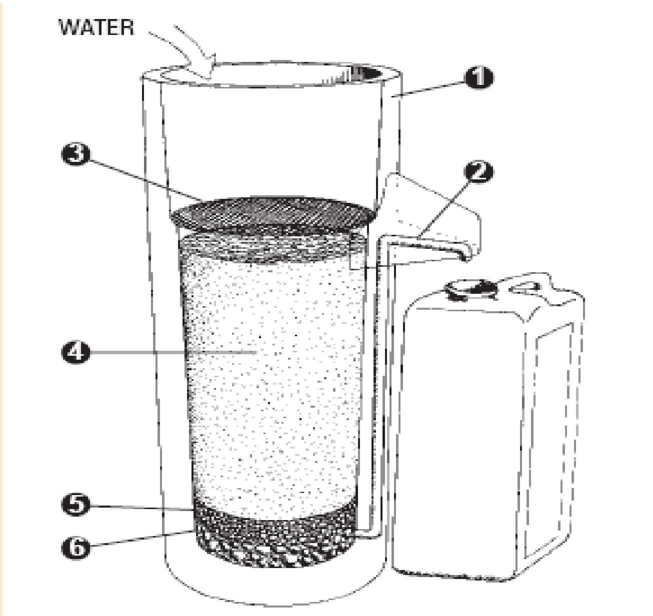

Figure 2.3: Illustration of a BSF unit

Each filter contains six components shown in figure 1:

- The concrete outer shell, built using ¼ to ½ sack of concrete mixed with some gravel and sand (1). Must be water tight, have sufficient depth for biological zone, allow enough volume for both storage of water prior to treatment and paused water within the sand bed.

- A length of PVC pipe (2). controls the standing water level of the supernatant
- A diffuser plate made from metal or pottery (3). Allows addition of water without disturbance of the sand bed.
- A 40cm layer of clean washed sand (4)
- A 5cm layer of small gravel (5)
- A 5cm layer of small stones or large gravel (6). ensures sand is not carried out of outlet pipe

The issues the BSF had to face were higher flow rates than the traditional slow sand filter, effective pathogen removal, improve the taste and appearance of the water, allow for intermittent flow, and still provide an appropriate technology for the developing world.

The function of the BSF begins with the raw water entering into the top of the filter where a diffuser plate is situated above the sand bed and dissipates the water at a regulated flow. The regulated flow is an important factor so as to prevent the disturbance of the biofilm. The water then travels slowly through the sand bed, followed by several layers of gravel, and then collects in a pipe located at the base of the filter. During this time, the water is driven through PVC piping and out of the filter for the user to collect the filtered water.

Majority of the filtration and turbidity removal occurs at the top layer of the sand bed due to the decreasing pore size caused by the deposition of particles. The BSF removes the pathogens through the same process as in slow sand filtration: as the suspended solids pass through the sand in the filter, they will collide and adsorb onto the sand particles. The processes by which the suspended solids collide and adsorb are straining and adsorption. The bacteria and suspended solids begin to increase in the greatest density at the top layer of the sand, leading to a gradual formation of the biofilm. The biofilm layer is also known as the Schmutzdecke (dirt blanket). The Schmutzdecke, which consists of algae, bacteria, and zooplankton, requires the water level to be 5cm above the biofilm in order to survive. As well, the biofilm needs both an aquatic environment and a constant influx of oxygen.

Therefore, if the water level above the biofilm rises above 5cm, the oxygen should not diffuse to the Schmutzdecke layer, which would lead to the suffocation of the biofilm. However, if the water falls below 5cm then the inflow of the water through the diffuser will disturb the biofilm. The 5cm water level is quite important to the efficiency of the BSF for the main reasons of preventing the sand from drying on the top layer, and to allow for sufficient oxygen to be maintained for the biolayer by having an outflow pipe in which the pipe stands 5cm above the top of the sand.

The biofilm involves a set of biological mechanisms in which it is not easy to pinpoint a specific mechanism that attributes to the removal, as the system operates in multiple biological and physical mechanisms. In laboratory and field testing, the BSF consistently reduces bacteria, on average, by 81-100 percent (Kaiser et al., 2002) and protozoa by 99.98-100 percent (Palmateer et al., 1999). Initial research has shown that the BSF removes less than 90 percent of indicator viruses (Mark Sobsey, 2005). The capacity of the vessel from the baseline water level to the lip of the container in the Manz design is about 20 liters.

2.4 Filtron(Ceramic) Filter

Filtron filters have traditionally been used for water treatment throughout the world. Currently, the most widely distributed ceramic filter is the Potters for Peace (PFP) filter, which was developed in 1981 by PFP, a non-profit organization based in the U.S. The final design was worked out by Ron Rivera, a ceramic artist in Nicaragua, during the 1990's. The Filtron has been distributed in many countries in Central America and Southeast Asia. It is illustrated in fig.2.4

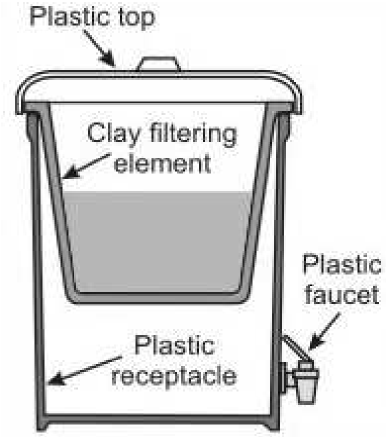

Figure 2.4: Filtron filter

The inner vessel is a ceramic pot formed in a mold which assures a standard size and shape. The pot is made from a proscribed mix of clay and graded sawdust. During the firing process, the sawdust burns creating a system of pores within the ceramic, allowing water to flow slowly through the vessel wall. After the pot has been fired, its inner and outer walls are painted with a colloidal silver[6] solution. The silver anion in this solution acts as a bacteriostatic agent, enhancing the filter's ability to remove bacteria (Lantagne DS. 2001.). however, the effectiveness of the filter in inactivating or removing viruses is unknown.

The pot holds seven liters and has a large lip so that it can be suspended within a commonly-available 20 liter plastic bucket as shown in Figure 2.4. A plastic tap is placed in the bucket near the bottom. The pots can be constructed in small factories, using locally available skills and materials. Quality control

[6] Colloidal silver—tiny silver particles suspended in liquid—is a disinfectant, preventing bacterial growth in the ceramic filter and assisting in inactivating the bacteria in the filter. The use of colloidal silver in the PFP filter does not leave a residual in the drinking water.

is performed by checking flow rates. Pots producing more than two liters per hour or less than one are to be rejected (Lantagne DS. 2001).

2.5. C# programming language

In the world of computing, the job of a computer programmer is to create programs that solve specific problems. The developed HFT Evaluation System™ is a software solution for evaluating the effectiveness of household water filters. The system allows the user to input data, view trend changes, analyze turbidity and faecal contamination of water samples run through different filters.

C# (pronounced C-sharp) is no doubt the language of choice in the .Net environment. It is a whole new language free of the backward compatibility curse with a whole bunch of new, exciting and promising features. It is an object oriented programming language and has at its core many similarities to Java, C++ and VB. In fact, C# combines the power and efficiency of C++, the simple and clean OO design of Java and the language simplification of Visual Basic. However, it is noted that literature concerning the usage of C# in water filtration technologies and its performance is either lacking or not documented.

Like Java, C# also does not allow multiple inheritance or the use of pointers (in safe/managed code), but does provide garbage memory collection at runtime, type and memory access checking. However, contrary to JAVA, C# maintains the unique useful operations of C++ like operator overloading, enumerations, pre-processor directives, pointers (in unmanaged/un-safe code), function pointers (in the form of delegates) and promises to have template support in the next versions. Like VB, it also supports the concept of properties (context sensitive fields). In addition to this, C# comes up with some new and exciting features such as reflections, attributes, marshalling, remoting, threads, streams, data access with ADO.Net.

The .Net Architecture and .Net Framework

Different important terms and concepts in the .Net Architecture and .Net Framework are discussed next:

The Common Language Runtime (CLR)

The most important concept of the .Net Framework is the existence and functionality of the .Net Common Language Runtime (CLR), also called .Net runtime for short. It is a framework layer that resides above the OS and handles the execution of all the .Net applications. HFTEval and other programs don't directly communicate with the OS but go through the CLR.

MSIL (Microsoft Intermediate Language) Code

When we compile our . Net program using any .Net compliant language (such as C#, VB.Net or C++.Net) our source code does not get converted into the executable binary code, but to an intermediate code known as MSIL which is interpreted by the Common Language Runtime. MSIL is operating system and hardware independent code. Upon program execution, this MSIL (intermediate code) is converted to binary executable code (native code). Cross language relationships are possible as the MSIL code is similar for each .Net language

Just In Time Compilers (JITers)

When the IL compiled code needs to be executed, the CLR invokes the JIT compiler, which compile the IL code to native executable code (.exe or .dll) that is designed for specific machine and OS. JITers in many ways are different from traditional compilers as they compile the IL to native code only when desired; e.g., when a function is called, the IL of the function's body is converted to native code *just in time*. So, the part of the code that is not used by that particular run is never converted to native code. If some IL code is converted to native code, then the next time it's needed, the CLR reuses the same (already compiled) copy without re-compiling. So, if a program runs for sometime assuming that all or most of the functions get called), then it won't have any just-in-time performance penalty.

As JITers are aware of the specific processor and OS at runtime, they can optimize the code extremely efficiently resulting in very robust applications. Also, since a JIT compiler knows the exact current state of executable code, they can also optimize the code by in-lining small function calls (like replacing body of small function when its called in a loop, saving the function call time).

The Framework Class Library (FCL)

The .Net Framework provides a huge framework (or Base) class Library (FCL) for common, usual tasks. FCL contains thousands of classes to provide access to Windows API and common functions like string manipulation, common data structures, IO, Streams, Threads, Security, Networking programming, windows programming, web programming, Data Access, etc. It is simply the largest standard library ever shipped with any development environment or programming language. The best part of this library is they follow extremely efficient OO design (design patterns) making their access and use very simple and predictable. You can use the classes in FCL in your program just as you use any other class. You can even apply inheritance and polymorphism to these classes.

The Common Language Specification (CLS)

Microsoft has released a small set of specifications that each language should meet to qualify as a .Net compliant Language. As IL is very rich language, it is not necessary to implement all the IL functionality; rather, it merely needs to meet a small subset of CLS to qualify as a .Net compliant language. This is the reason why so many languages (procedural and OO) are now running under the .Net umbrella. CLS basically addresses language design issues and lays down certain standards. For instance, there shouldn't be any global function declarations, no pointers, no multiple inheritance and things like that. The important point to note here is that if you keep your code within the CLS boundary, your code is guaranteed to be usable in any other .Net language.

The Common Type System (CTS)

.Net also defines a common Type System (CTS). Like CLS, CTS is also a set of standards. CTS defines the basic data types that IL understands. Each .Net compliant language should map its data types to these standard data types. This makes it possible for the 2 languages to communicate with each other by passing/receiving parameters to and from each other. For example, CTS defines a type, int32, an integral data type of 32 bits (4 bytes) which is mapped by C# through **int** and VB.Net through its **integer** data type.

Garbage Collection (GC)

CLR also contains the Garbage Collector (GC), which runs in a low-priority thread and checks for un-referenced, dynamically allocated memory space. If it finds some data that is no longer referenced by any variable/reference, it re-claims it and returns it to the OS. The presence of a standard Garbage Collector frees the programmer from keeping track of dangling data.

The .Net Framework

The .Net Framework is the combination of layers of CLR, FCL, Data and XML classes and our windows, Web applications and web services. A diagram of the .Net Framework is presented below.

The Visual Studio.Net IDE

Microsoft Visual Studio.Net is an integral Development Environment (IDE), which is the successor of Visual Studio 6. It eases the development process of the .Net application (VC#.Net, VB.Net, VC++.Net, Jscript.Net, J#.Net, ASP.Net, and more). The revolutionary approach in this new improved version is that for all the Visual Studio.Net Compliant Languages use the same IDE, debugger, project and solution explorer, class view, properties tab, tool box, standard menu and toolbars. The key features of Visual Studio.Net include: the IDE provides various useful development tools such as:

- Keyword and syntax highlighting
- Intellisense (auto complete), which helps by automatically completing the syntax as you type a dot (.) with objects, enumerations, namespaces and when you use the "New" keyword.
- Project and solution management with solution explorer that helps to manage applications consisting multiple files.
- Help building user interface with simple drag and drop support.
- Properties tab that allow you to set different properties for multiple windows and web controls.
- Standard debugger that allows you to debug your program using putting break points for observing run-time behavior.
- Hot compiler that checks the syntax of your code as you type it and error notification.
- Dynamic Help on a number of topics using the Microsoft Development Network (MSDN) library.
- Compiling and building applications
- Program Execution with or without the debugger.
- Deploying your .Net application over the internet or to disk.

Projects and Solutions

A project is a combination of executable and library files that make an application or module. A project's information is usually placed in a file with the extension '.csproj' where 'cs' represents C-Sharp. Similarly, VB.Net projects are stored as 'vbproj' files. There are several different kinds of projects such as Console Applications, Windows applications, ASP.Net Web applications, class Libraries and more.

A solution on the other hand is a placeholder for different logically related projects that make some application. For example, a solution may consist of an ASP.Net Web Application project and a windows Form project. The information for a solution is stored in '.sln' files and can be managed using Visual Studio.Net's Solution Explorer. Solutions are similar to VB 6's Project Group and VC++ 6's workspace.

Toolbox, Properties and Class View Tabs

Now there is a single toolbox for all the Visual Studio.Net's languages and tools. The toolbox (usually present on the left hand side) contains a number of common controls for windows, web and data applications like the text box, check box, tree view, list box, menus, files open dialog etc

- The properties Tab (usually present on the right hand side in the IDE) allows you to set the properties on controls and forms without getting into code.
- The Class View Tab shows all the classes that your project contains along with the methods and field in tree hierarchy. This similar to VC++ 6's class view.

2.6 Literature Review Conclusion

Household water treatment and safe storage technologies have gained momentum in the last decade and are more and more embraced in developing countries. However, available literature on implementation focuses more on socio-economic aspects at the expense of technical performance parameters. It is worthy indicating here that studies on these parameters are either not available or if available they have not been collected and collated in documentary evidence. This coupled with the fact that literature concerning usage of C# in water filtration technologies and its performance is also lacking or not documented calls for actors to channel more effort towards this study area.

Materials and methods

3.1. Study area

The Mandera is one of the arid districts of Kenya with an erratic mean annual rainfall of 255mm, mean temperatures of 28 degrees Celsius and a projected population of 330,284 persons by 2008 based on 1999 census, 2009 census figures from this region have been disputed and the matter is being litigated in the high court of Kenya. It shares borders with Ethiopia to the north, Somalia to the East and larger Wajir District of Kenya to the South.

The area is divided into three districts namely Mandera East, Mandera Central and Mandera West. Mandera , Takaba and Elwak are the only gazetted urban centres and accommodate majority of the peri-urban poor. With an area of 26,470 sq kms the larger mandera has 1300 km of classified road network of earth surface which become impassable when impounded with rains.

There are three main livelihood zones in the district i.e. a pastoral economy zone in the east and agro-pastoral economy zone in the west and an irrigated cropping zone in the north along the Daua river. The population ratio in these zones represent pastoral zone of 28.43%, agro-pastoral zone of 39.24% and irrigated cropping zone of 32.42% (there is mixed of livelihood of agro-pastoralism).

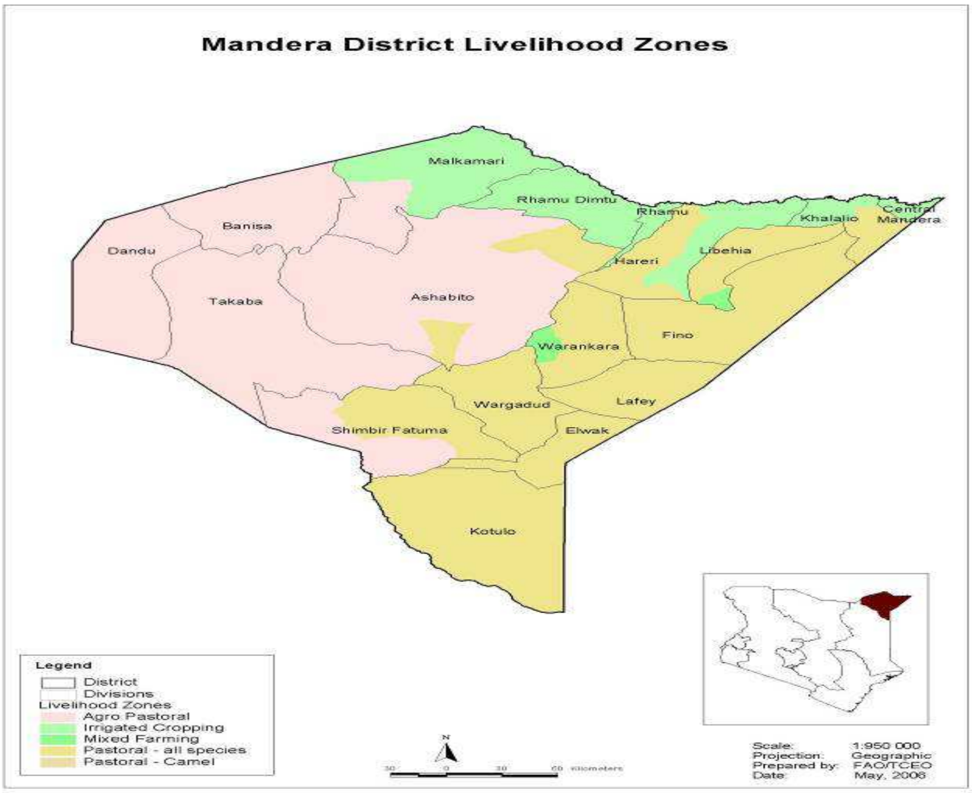

Figure 3.1: Mandera District Location and Livelihood Zones, Source: KBS

The River Daua is the only natural water source in the district, but the supply is unreliable 3-4 months every year. The population relies on hand dug shallow wells and boreholes. However, the ground water potential is low, especially in the dry western part of the district. Most boreholes have a low yield (1.3-5 m3/hour), there are some water pans that collect surface run-off during the wet season, but the evaporation rate is very high attributed to high temperatures. The water in some dams is blackish due to high contents of black soils in the surrounding area and in many cases water is also silt-laden, due to the erosion caused by flash floods and lack of maintenance. Due to siltation, the dams' lifespan is usually very short.

The coverage of publicly supplied piped water is very low, due to the very low population density. The water supply in Madera Town serves only 25 per cent of the population and does not reach the suburbs. fast growth of the town coupled with lack of financial resources as also posed challenges in water supply infrastructure expansion. On the other hand the existing system as not incorporated any treatment plant within the system thus most often than not water quality supplied to the resident is compromised

Water points are scattered and distant from the human settlements. In urban areas, the average distance to the nearest water source is 0-1 km. In non-urban areas, the distance is 5km in central division and 15-30km in other divisions. The foregoing is worse during dry spells as most sources are rendered dry.

The quality of the water in the district is often poor, especially in the case of earth pans, due to the concentration of livestock around the water source. The risk of water borne diseases greatly increases during the periods of drought, a factor attributed to the use of water from these unsafe sources. The situation exacerbates at the onset of rains since water becomes muddy or contaminated with rotting animal carcases and human waste. Rains can also cause the collapse and silting of dams, aggravating the problem of water shortage and quality.

In Mandera, most people – predominately women – spend a portion of their day collecting, carrying and storing water for drinking. Bacteriological water quality testing for fecal coli forms per 100ml of water (FC/100ml) at household level reveals that: 15.0% had potable water, 4.1% had low risk water, 25.4% had contaminated water, and 53.3 % had extremely contaminated water whereas 2.2% of the results were inconclusive. This indicates that 79% of households do not have access to safe drinking water. (ACF, 2008), over the years this has affected pastoral livelihoods, forcing many households into destitution in new settlements, urban centres, and rural villages. As a result, a lot of new settlements are mushrooming in many parts of the three districts, posing serious environmental threats to the already fragile ecosystem and are a burden to service provision by the government and other development actors. The District Steering Groups from the three districts have discouraged the new settlements and have asked the residents to shift to nearby bigger established centres.

3.2. Data sources and Materials

The following materials and equipments were used for data collection:

- Three concrete bio-sand filters readymade,
- Three complete ceramic filters
- Six, twenty liter jerricans,
- Six, ten liter buckets and,
- Delagua kit
- Normal watch

Water was run through the filters for a period of thirty four continuous days. For consistency, water samples used in this study were drawn directly from the community fetching point along River Daua. The procedure below was employed while preparing for data collection: Small stones, gravel and sand layers were washed separately in water by stirring and pouring dirty water. This was repeated until clear water was obtained. The biosand filters were prepared by filling them with cleaned layers of small stones, gravel and sand, also inserted were the diffuser plates as filters set in place. Similarly, ceramic filters were cleaned thoroughly with clean water and filters were labeled as BSF1, BSF 2, BSF 3, CF1,CF2 and CF3 for biosand and ceramic respectively.

During field operations the following sequence of steps was carried as routine to collect data:

1. Collect six water samples in a 20Litre container each from the source (River Daua)
2. Label the samples correctly depending on their source, date and location e.g. river Tana, 02/02/2009, Garissa)

3. From the 20Litre sample, pour a sub sample into a turbidity testing tube (having a capacity of 500mL), read and record it's turbidity value under **Raw water** (under the turbidity subtitle in the data entry table).
4. Similarly take a sub sample of 100mL from the main 20L sample and use it to determine its faecal pollution (through the DelAgua Kit procedure). Record this value under **Raw water** (under the Faecal count subtitle in the data entry table)
5. Pour the sub sample in 3 above back to the main 20Litre sample.
6. Now pour the 20Litre sample gently into the filter.
7. As soon as the water starts to come out of the filter outlet spout, collect a 100mL sample of the first few drops and use it to determine level of faecal pollution (through DelAgua Kit procedure). This sample represents water which stays in the filter for sometime (ranging from 1 hour to 24 hrs). Record it under **Filtered water (OvN)** under the Faecal count. **Note: OvN is abbreviation for overnight**
8. Using a stop watch and a graduated beaker record the cumulative volume filtered at intervals of 4 minutes for Biosand filter and 60 minutes for ceramic Filter. This is recorded under **Volume** with its corresponding cumulative time noted under **Duration.**
9. As the water passes through the filter, take a filtered sample and pour it into a turbidity tube to determine its turbidity. Record this value under **Filtered water** (under the turbidity subtitle in the table for entering data)
10. Similarly collect a 100mL sample of filtered water as it passes through the filter and determine its faecal pollution (DelAgua Kit procedure). This sample represents water which is filtered as soon as it is passed through the filter. Record this value under **Filtered water (SD)** in the Faecal count. **Note: SD is abbreviation for same day**

The data was then presented in a tabular form as below:

Date/Day	Turbidity (NTU)		**Filter Flow (cumulative)**		Faecal Pollution (FC/100mL)		
	Raw water(1,2,3…)	Filtered water(1,2,3…)	Volume (L-1,2,3…)	Duration (Minutes-1,2,3….)	Raw water (1,2,3…)	Filtered water (OvN-1,2,3…)	Filtered water (SD-1,2,3…)

Note: the (1,2,3…) shows that we have more than one filter for each different filter technology e.g. Raw water (1,2,3…)*: the format of the database in table above is comprehensive (it has all raw data)*

Data Results

The tests were carried out for thirty four days and the results tabulated respectively for each filter (As in the appendix). After which it was fed into the program.

3.3. Computer program development

A program which provides user friendly interface for comparing the performance of household water treatment and safe storage technologies has been be realized through a multi-step process called program development. The later involved a five-step process requiring understanding of the problem at hand, developing a solution, writing a program, testing the program, and maintaining it. Here is an outline of each step:

3.3.1. Problem Analysis

The first step for this development process was to understand the problem. During the step, a careful analysis of household water treatment and safe storage technology performance was made, in order to form a precise specification that included the input required and the type of output needed. Input refers to the specific data that is put into a problem in order for it to be solved. Output refers to the exact answer that must be produced from the problem. In view of the foregoing then the HFT Evaluation System™ program was developed to perform the following purpose;

- Allows the user to view trend changes in faecal contamination and turbidity for water run through a filter
- Permits a graphical representation of the processes for each filter
- Allow a graphical representations comparing technologies against set standards for different parameters
- Establishes a rule for each technology (general trend/behavior)
- Enables choice of the best water filter options based on technical considerations through filter efficiency and effectiveness comparison.

3.3.2. Develop an Algorithm/Requirement Specification

Overall purpose of system

A system to compare the performance of various filtration technologies (household water treatment and safe storage)

What it must do:

1. Allows the user to view trend changes in faecal contamination and turbidity for water run through a filter
2. A graphical representation of the processes for each filter
3. A graphical representations comparing technologies against set standards for different parameters
4. Establish a rule for each technology (general trend/behavior)
5. Choose a better option based on technical considerations (afford comparison of different filters)

The user interface will contain /or will be in:

1. A stand alone computer /laptop
2. Either enter Data directly (through the keyboard) or access by the program from a database

Upon opening the program, the user should experience the following sequence of events:

1. The screen should displays a welcome message and allows the user to enter the name of the technology (e.g. biosand, ceramic etc) or select Options from a drop down menu. Choosing an available option authenticates the user.
2. If the authentication process is successful, the main menu displays numbered options for data entry, performance analyses: flow rate, turbidity, faecal pollution and option for reports. The main menu also displays an option that allows the user to exit the system at this point.

Main menu 1 – Enter Sample Data 2 – Filter Performance Analysis 3 – Reports 4 - Exit

The user either chooses to perform an operation from one of the above option or exits.

Now this is what should happen for each option:

Option A: Enter Data Sample

1. The user should choose the number of filters to analyze (say 1-4), or cancel to return to the main menu. Note: should make it easier to look/analyze results from various/different tests, even locations.

No of filters:
1:
2:
3:
4:

Enter Cancel

2. The user is further prompted to enter the test data/ or access it from a database. The solution should enable data manipulation like editing, uploading and saving in readiness for filter analyzes.

Option B: Filter Performance Analysis

Under this option the program should enable three different analyses to take place, viz; flow rate, turbidity and faecal pollution.

B1: Filter Flow Analysis

User should be able to display (view) the following:

1. Map in graphical representation the trend of filtration duration for each filter
2. Graphical representation of the raw data. The cumulative volume filtered is on the Y-axis whereas the x-axis takes cumulative duration. [These values are

laid out clearly in the database]. The result is a straight line graph starting from coordinate (0, 0) i.e. origin.

3. Gradient of the line of above. Calculated by any two arbitrary points on the graph and using their coordinates. Change in Y/change in X, this should be displayed with correct units.

   For example:

   Say If the line passes points (1,2) and (4,7) then,

   Gradient = change in Y/change in X

   = (7-2)/4-1)

   = 1.7 L/min **(this is the flow rate for that filter)**

4. Affords a comparison against acceptable water quantities required for drinking according to sphere, WHO or any other local standard for an average family. For example 3Litres/person /day is the maximum according to sphere project, Humanitarian charter and minimum standards in disaster response, 2004). Then the question is within a selected duration (say 2 hours) how many litres can the filter under study produce? [Gradient *120 to give litres filtered in 2hrs,].

   Drinking water requirement per family

   Number of family members = A (A is a whole number e.g. 6,7, 10,13 etc, but should be more than 3 – the assumption is each family has at least two parents and one child)

   Drinking Volume/person/day = B Litres (B can be a decimal point number which represents a drinking water standard under consideration)

   Water required/family/day = A*B

   = C Litres

   Filtered water/Filter/2 hours = Gradient * 120 (2 hours in minutes is 120)

   = D Litres

If :

(C<D, "The filter meets the family drinking water requirements, hence recommended". Otherwise it should say, flow rate not appropriate). **Note: this step is performed for each and every filter as a separate entity, before comparing them.**

5. Depending on the number of filters, the program should compare them based on this parameter and return a grading from the one with the highest flow rate to the least while quoting their respective rates and finally saying the one (technology) with the highest flow rate is the best for this parameter.[filter type 1 has a flow rate of……….L/min, filter type 2 has a flow rate of …..L/min e.t.c. therefore filter (say type 1, 2 or 3) has the highest flow rate and thus is the best for this parameter. Note: remember that flow rate is represented by the Gradient

B2: Analyze Turbidity

Under this category the program should;

1. Graphical representation of the data (3 distinct series; raw water, filtered water and third series for the standard of sphere i.e. 5NTU). These lines need not be straight. They can take any shape. The Y-axis will take Turbidity (NTU), while the X-axis will take the date (or day i.e. instead of dates we can call them by day1, day2, day3 etc., which represent the numerical day from beginning of test runs)

   This presents an opportunity for someone to view on the same layout the effect of the filter on turbidity without any calculations. It requires plotting turbidity on Y-axis and date/day on X-axis. One line to represent raw water (using all recorded raw water points) and another second different line to represent filtered water (using all recorded filtered water points, where each filtered water point correspond to a raw water point in the table)

2. Overall percentage reduction (By what percentage can the filter reduce turbidity?)

   This is calculated for each and every raw/filtered water result as presented in the table above

   = {(Raw water turbidity – filtered water turbidity)/(raw water turbidity)}* 100.

   The results should be tabulated in a column named **'% Reduction**' under the Turbidity subtitle

3. Evaluation [is reduction less than 5NTU] for all sets of results, if not to what percentage does it achieve required turbidity levels.Count number [points] of results below 5NTU and divide by the total number [points] of result then multiply by 100)

   To calculate:

a) In the column filtered water (under turbidity).
b) Pick the first value (say T) for turbidity. Set the program to count the values as they are checked. For example if a value has been checked, the counter should keep 1.
c) Test it with the condition (If T<=5).
d) If the condition is true then, record that value as 1, otherwise return 0
e) Go to the second (next) value and increment the counter by 1(i.e. Add 1 to the 1 in step b to make it 2).
f) Repeat step c
g) If step c is true, add 1 to the recorded value in step d, otherwise add 0 (i.e keep the recorded value in step d)
h) Repeat steps e, f and g until all values in the column are checked.
i) After all values are checked. Divide the final recorded value in step h by final counter value then multiply by 100.
j) Then output the result as. "The Filter reduces Turbidity to acceptable level by ………..%" (the dashed part is for the figure output in step i)

- Comparing filters: If the percentage above is >90% then the filter passes the test of achieving required turbidity levels and should be displayed as so i.e. [filter 1,2……e.t.c. is recommended for turbidity reduction, otherwise not recommended]

B3: Analyze faecal pollution

The user should be able to view:

1. Graphical representation of the data (4 distinct series/categories; raw water data , filtered water(OvN and SD separately) data and third straight line for low risk water [FC/100ml<10]. These lines need not be straight. They can take any shape. The data recorded in table (section for flow rate) above is to be used. The Y-axis will take Faecal count (FC/100mL), while the X-axis will take the date (or day i.e. instead of dates we can call them by day1, day2, day3 etc). the output should be three straight lines showing general trends {for raw and filtered water(OvN and SD) respectively} thus presents an opportunity for someone to view on the same layout the effect of the filter on faecal pollution without any calculations.

   It requires plotting Faecal count on Y-axis and date/day on X-axis. One line to represent raw water (using all recorded raw water points) and two other different lines to represent filtered water (using all recorded filtered water points)
2. Overall percentage reduction [calculated the same way as in B2 above, for the same step]. It is calculated for each and every raw/filtered (OvN and SD) water result.

   = {(Raw water faecal count – filtered water faecal count)/ (raw water faecal count)}* 100.

   The results should be tabulated in two different columns named **'% Reduction (OvN) and % Reduction (SD)**' under the Coliform count subtitle
3. Evaluation [which class of water it provides, according to WHO and sphere standards i.e. potable(If FC/100ml=0), low risk(If 0<FC/100ml<10),

contaminated(If 10<FC/100ml<200) or extremely contaminated(If FC/100ml>200]

To enable evaluation to take place, the following steps have to be followed:

a) Go to the column labeled **Filtered water (SD),**
b) Place the cursor in the cell containing the first value,
c) While in that first cell set a counter to zero (0).
d) Then increment it by 1. To show that the cell has been counted,
e) Set four parameters; **portable, low risk, contaminated and extremely contaminated**. They will help to store another counting depending on condition in step f. All parameters can be initialized to zero,
f) Test the value in that cell with the each of the four condition sequentially ;

   If (Value =0), if true then increment **portable** by 1 and move to step g (if the condition is false test for the next condition)

   If (Value<=10), if true then increment **low risk** by 1 and move to step g (if the condition is false test for the next third condition)

   If (10<Value<200), if true then increment **contaminated** by 1 and move to step g (if the condition is false, then automatically increment **extremely contaminated** by 1 and move to step g.
g) Now after finishing step f, move the cursor to the next cell.
h) Now increment the counter by 1,
i) Then repeat step f,
j) Repeat steps g,h and i until all values in column filtered water (SD) are tested,
k) Now do the following calculation:

   = (portable/counter)*100

   = Result 1

   NB: repeat the same calculation for low risk, contaminated and extremely contaminated. Only replacing portable with each in turn to get Result 2,3 and 4.

l) Then output the result as:

"The filter produces:
Result 1 % of portable water
Result 2 % of low risk water
Result 3 % of contaminated water and
Result 4 % of extremely contaminated water"
In comparing across filters, the display should show if safe or unsafe. [If portable or low risk then the filter is classified as "SAFE", otherwise it is "UNSAFE" to use.

Option C: Reports
Once developed and running, the program will be enabled to produce reports for all the data entry and analyses performed on it.

Option D: Exit
This will provide for a mechanism to go back to the welcome screen

3.3.3. Program Code

After a solution had been developed, the next step of the process was to write the program code. The algorithm was converted into C# computer programming language. This was done systematically, starting at the beginning of the algorithm, down to the end. The program code was well-structured and includes adequate documentation. Documentation is statements written in the program code that does not affect the code itself, but lets the programmer know what specific parts of the code is supposed to do.

The program developed has been named HFT Evaluation system which is linked to its core functionality. HFT Evaluation System™ is a software solution for evaluating the effectiveness of household water filters. The system allows the user to input data, view trend changes, analyze turbidity and faecal contamination of water samples run through different technology filters used at household level.

The system is designed to display tabular and graphical representation of data and analyze the data for turbidity levels and faecal pollution parameters. This system is primarily designed to analyze data samples for three types of filters but may be scaled upwards in future to analyze data samples for more filter types. It is worth noting that the system can handle three different filters for each technology, analyze data for each filter and even compare the performance of each filter against the other filters.

HFT Evaluation System™ is developed using the modular software design approach and object-oriented design. It employs the singleton design pattern that allows classes to inherit from only one base class. The benefits derived from this design approach are enormous. Firstly, it removes the ambiguity and confusion that comes with multiple inheritance methodologies and programming languages. It also affords maintainability of source code by other persons or teams and makes it easier to read code written by other programmers. It is also argued that the singleton approach makes programmers to design highly optimized software especially when implementing threading (ability for a single program to perform several tasks at the same time).

Technology Stack

The system was developed using free Microsoft software development tools which are downloadable from the official Microsoft© website (www.Microsoft.com/net).

The language of choice for developing the system was C# (pronounced C-Sharp). C# is the current language of choice for new Microsoft Windows-based projects and uses the powerful Microsoft .NET Framework, a languageneutral, heterogeneous framework for developing modern component-oriented software on the Microsoft Windows system.

C# is a modern object-oriented and component-oriented language developed by Microsoft for the .NET framework, based on C/C++ and Java and is very easy to learn especially for future maintainability of the system.

The syntax is similar to C/C++ but it doesn't have the complexities of those languages as you can begin to be productive with it in a matter of days if you already know C/C++. For example C# enforces strict object-oriented software construction unlike C/C++. Classes written in C# will not compile if object-oriented rules are not observed.

C# is currently one of the most widely used and fastest growing programming languages according to www.TIOBE.com (a website dedicated and recognized for ranking

Programming languages in the world)

The technology stack used for developing the system comprises the following Microsoft technology stack:

i) Microsoft .NET Framework Software Development Kit (SDK).

vi) Microsoft C# Language Compiler and Debugger

vii) Microsoft .NET Framework Redistributable Kit

viii) Microsoft Visual Studio Development Kit (Express Version)

ix) Microsoft Access Database Engine

This software is available for free download from the www.Microsoft.com/net website.

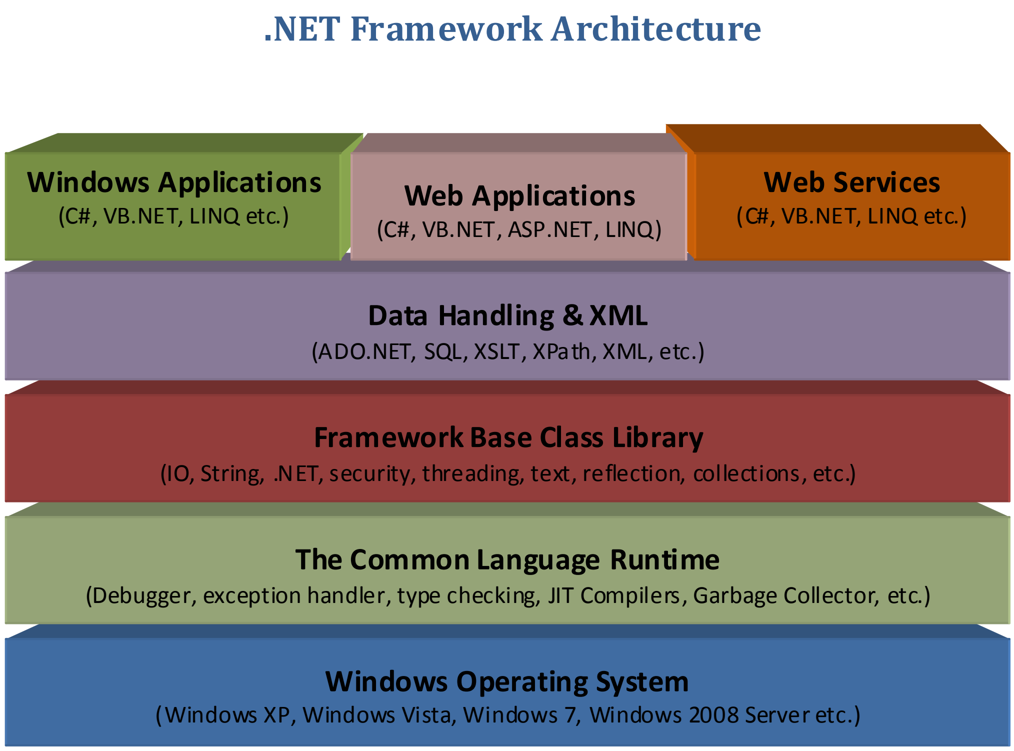

Figure 3.2: the .NET framework architecture

Glossary

In order to understand the HFT system code, the following terms and abbreviation are elucidated under glossary and references;

- **.NET Framework** – A modern Microsoft© Windows-based software development environment for developing Desktop, Internet applications and Web Services.
- **C#** – A modern object-oriented and component-oriented language based on C/C++ and Java, developed by Microsoft for developing software on the .NET Platform.
- **.NET SDK** – The Microsoft .NET development kit comprising the C# Language compiler and debugger.
- **Microsoft Visual Studio™** - A rich, comprehensive GUI-based Interactive Development Environment (IDE) for developing software on the Microsoft Windows operating systems.

- **CLR –** Common Language Runtime is the .NET runtime environment, language interpreter and compiler similar to the Java Virtual Machine.
- **IL –** .NET Intermediate Language is the intermediate code emitted by the CLR.
- **.NET Runtime environment –** A runtime environment for software developed in .NET Framework. The .NET Framework, the C#.NET or VB.Net programming languages, .NET SDK, Compiler, Microsoft Visual Studio™, Debugger and the .NET Runtime environment are collectively referred to as the .NET Platform.
- **ADO.NET -** ***A**ctiveX **D**ata **O**bjects,* Microsoft's high-level interface for data objects.
- **XML -** ***Ex**tensible **M**arkup **L**anguage,* a specification developed by the W3C. XML is a pared-down version of SGML, designed especially for Web documents.
- **GUI –** Graphics User Interface
- **Microsoft Access –** A common database management system developed by Microsoft.
- **Object Oriented Programming –** A modular software design methodology used for developing this solution. OOP is used for developing highly re-useable software components and employs the three major features of object-oriented design namely, *Abstraction*, *Inheritance* and *Polymorphism*.
- **Component –** A highly re-usable software assembly, Class or DLL that can be easily integrated into new software projects with minimum or no modifications.
- **DLL –** Dynamically Linked Library, is a compiled software component which can run on its own or can be assembled together with other software to develop a larger application.

References

Table 3.4: code reference table

Reference	**Description**
HFTEvalApplication	This is the name of the application and the namespace
Properties	Properties and meta data for the project – contains Assembly info data, resources, settings and Database connection strings
References	Microsoft.NET Class reference library (these comprise the .NET Classes (DLLs) that can be included in this project)
. csproj	Microsoft C#.NET project file
.sln	Microsoft.NET solution file extension
.cs	Microsoft C# Class file extension
.resx	.NET project resource files
.exe	Microsoft executable file
bin	Binary folder
images	Images folder
Resources	.NET Project resource file/folder
app.config	Application configuration file
Program.cs	The Main Class (Contains the Main.cs method)

	(This is the entry point for the solution)
Settings.cs	.NET settings file for the project
StartUpForm.cs	This is the start-up Form for the project
MainMnu.cs	Main menu for this solution
BiosandFilter1.cs	Biosand Filter data entry Class for 1 filter
BiosandFilter1.Designer.cs	BiosandFilter1.cs form designer Class
BiosandFilter2.cs	Biosand Filter data entry Class for 2 filters
BiosandFilter2.Designer.cs	BiosandFilter2.cs form designer Class
BiosandFilter3.cs	Biosand Filter data entry Class for 3 filters
BiosandFilter3.Designer.cs	BiosandFilter3 form designer Class
BiosandFilter4.cs	Biosand Filter data entry Class for 4 filters
BiosandFilter4.Designer.cs	BiosandFilter4 form designer Class
CeramicFilter1.cs	Ceramic Filter data entry Class for 1 filter
CeramicFilter1.Designer.cs	CeramicFilter1.cs form designer Class
CeramicFilter2.cs	Ceramic Filter data entry Class for

	2 filters
CeramicFilter2.Designer.cs	CeramicFilter2.cs form designer Class
CeramicFilter3.cs	Ceramic Filter data entry Class for 3 filters
CeramicFilter3.Designer.cs	CeramicFilter3.cs form designer Class
CeramicFilter4.cs	Ceramic Filter data entry Class for 4 filters
CeramicFilter4.Designer.cs	CeramicFilter4.cs form designer Class
OtherFilter1.cs	Other Filter data entry Class for 1 filter
OtherFilter1.Designer.cs	OtherFilter1.cs form designer Class
OtherFilter2.cs	Other Filter data entry Class for 2 filters
OtherFilter2.Designer.cs	OtherFilter2.cs form designer Class
OtherFilter3.cs	Other Filter data entry Class for 3 filters
OtherFilter3.Designer.cs	OtherFilter3.cs form designer Class
OtherFilter4.cs	Other Filter data entry Class for 4 filters
OtherFilter4.Designer.cs	OtherFilter4.cs form designer

	Class
DrinkingRequirements1.cs	Entry form for drinking water requirements
DrinkingRequirements1.Designer.cs	DrinkingRequirements1.cs form designer Class
DrinkingRequirements2.cs	Water drinking requirements per family
DrinkingRequirements2.Designer.cs	DrinkingRequirements2.cs form designer Class
Evaluation1.cs	Filter Evaluation (Turbidity)
Evaluation1.Designer.cs	Evaluation1.cs form designer Class
Evaluation2.cs	Filter Evaluation (Faecal Contamination)
Evaluation2.Designer.cs	Evaluation2.cs form designer Class
FilterSelectionDialog1.cs	Filter Selection Form 1
FilterSelectionDialog1.Designer.cs	FilterSelectionDialog1.cs form designer Class
FilterSelectionDialog2.cs	Filter Selection Form 2
FilterSelectionDialog2.Designer.cs	FilterSelectionDialog2.cs form designer Class
PerformFilterTests.cs	Perform Filter tests dialog box
PerformFilterTests.Designer.cs	PerformFilterTests.cs form designer Class
FilterFlowChart1.cs	Filter flow duration

FilterFlowChart1.Designer.cs	FilterFlowChart1.cs form designer Class
FilterFlowChart2.cs	Average filter flow rate
FilterFlowChart2.Designer.cs	FilterFlowChart2.cs form designer Class
TurbidityChart1.cs	General turbidity trends
TurbidityChart1.Designer.cs	TurbidityChart1.cs form designer Class
TurbidityChart2.cs	Comparison against international standards (WHO, sphere etc.)
TurbidityChart2.Designer.cs	TurbidityChart2.cs form designer Class
TurbidityChart3.cs	Percentage reduction per filter
TurbidityChart3.Designer.cs	TurbidityChart3.cs form designer Class
FaecalPollutionChart1.cs	Faecal pollution per filter
FaecalPollutionChart1.Designer.cs	FaecalPollutionChart1.cs form designer Class
FaecalPollutionChart2.cs	Faecal pollution reduction per filter
FaecalPollutionChart2.Designer.cs	FaecalPollutionChart2.cs form designer Class
TabularData1.cs	Tabulation of percentage reduction turbidity per filter
TabularData1.Designer.cs	TabularData1.cs form designer Class
TabularData2.cs	Tabulation of percentage reduction

	faecal pollution per filter
TabularData2.Designer.cs	TabularData2.cs form designer Class
HFTDatabase.accdb	Microsoft Access Database
HFTDatabaseDataSet.xsd	Microsoft Access Database Schema

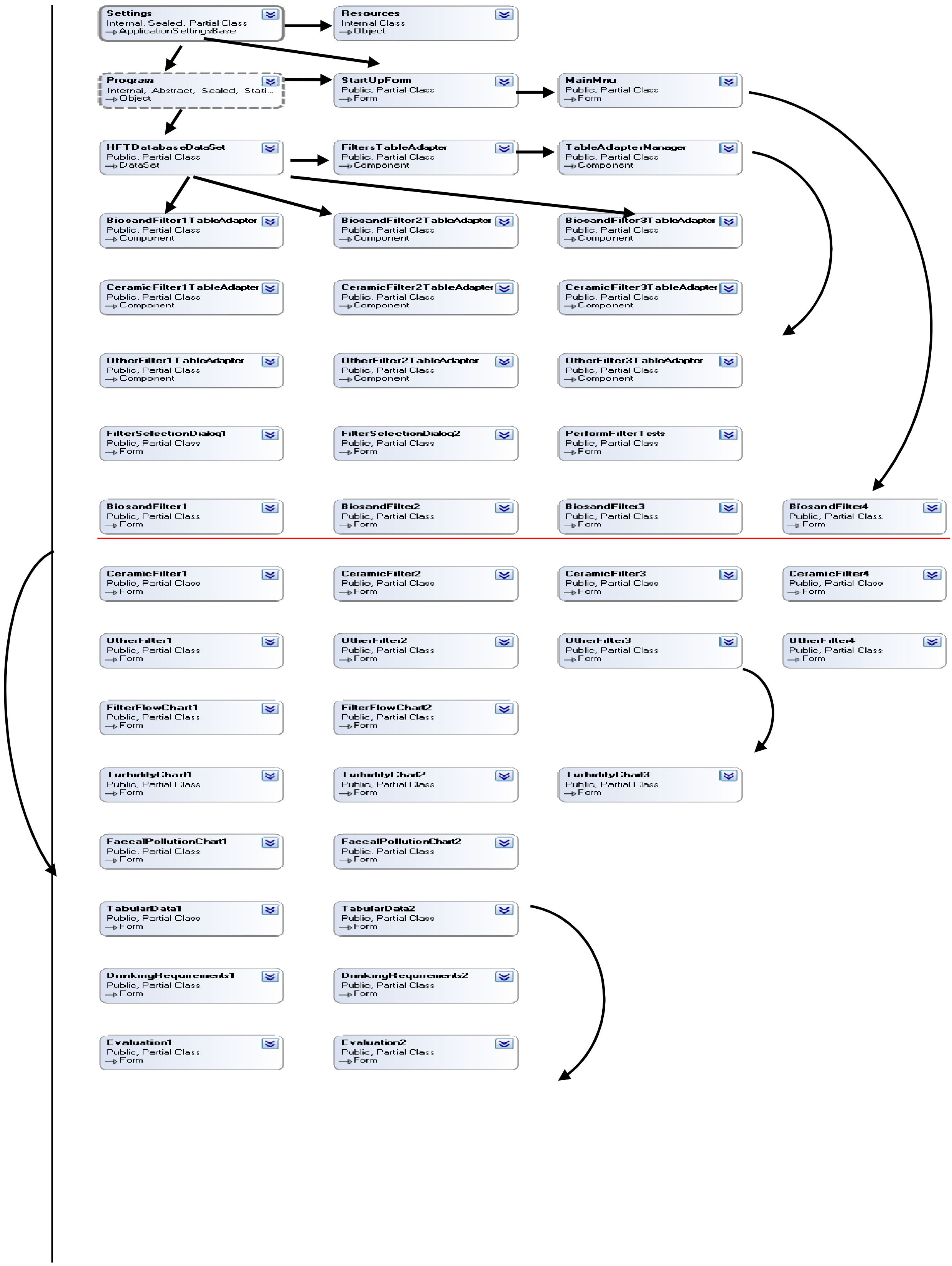

Figure 3.3: code class diagram

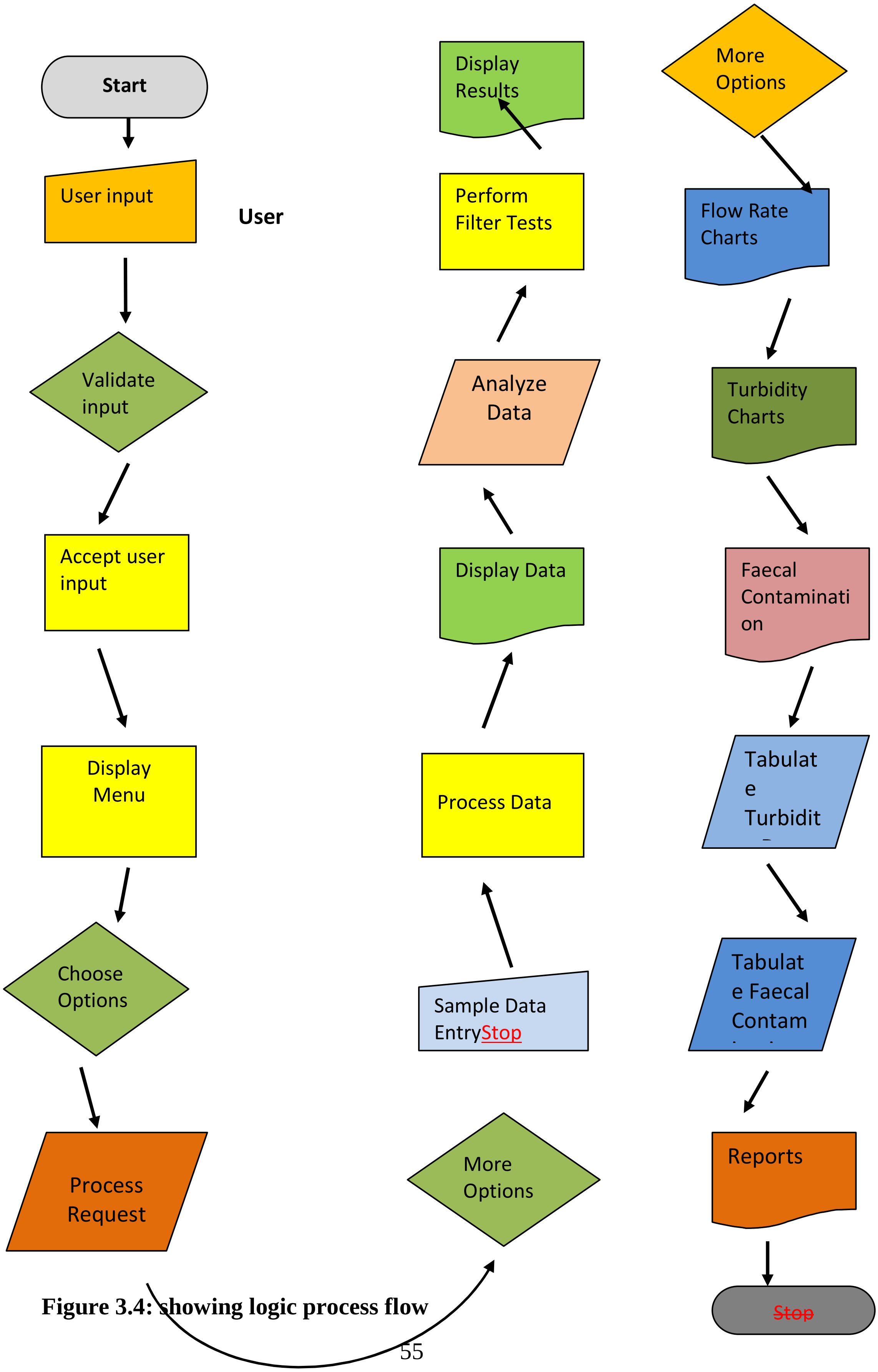

Figure 3.4: showing logic process flow

Database Schema

The solution uses the Microsoft Access Database. The database is organized into **10** data tables namely **BiosandFilter1**, **BiosandFilter2**, **BiosandFilter3, CeramicFilter1**, **CeramicFilter2**, **CeramicFilter3**, **OtherFilter1**, **OtherFilter2**, **OtherFilter3** and **Filters** table as per the following table layout and database schema:

Each table represents the number of filter sample data that can be stored in the table.

For example BiosandFilter1 can store data for only 1 filter; BiosandFilter2 can store data for 2 filters and son on…

Table Layout

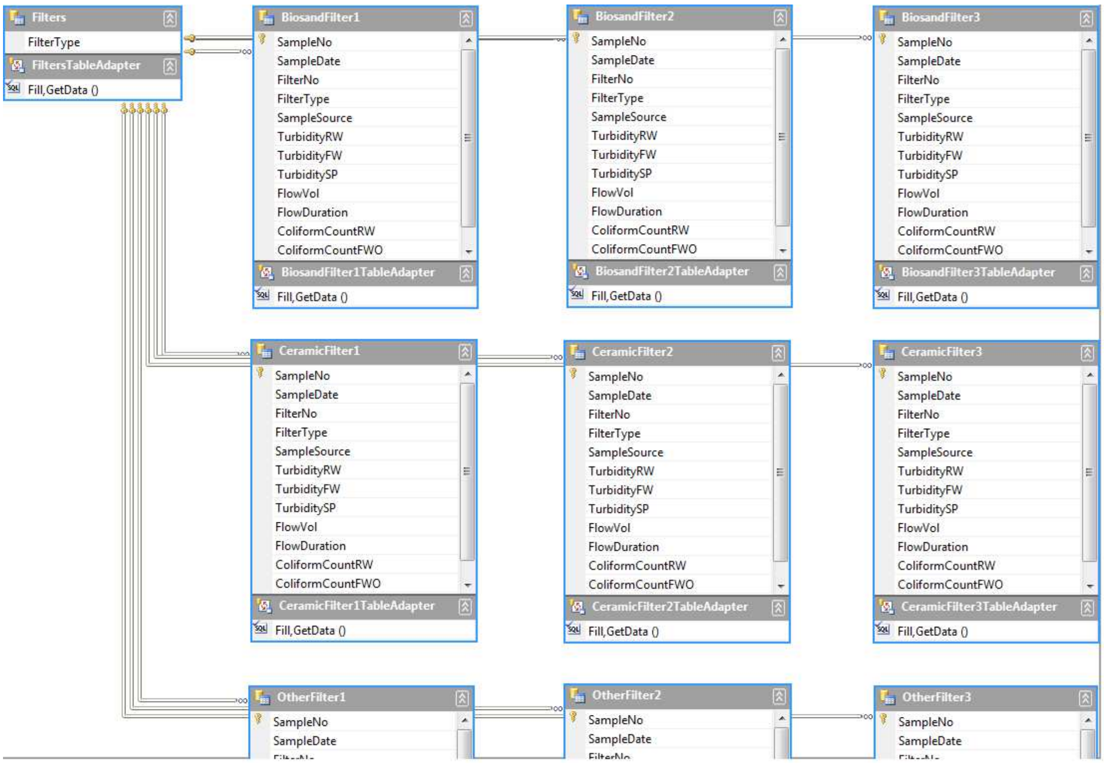

Figure 3.5: showing database schema, table layout

Database Schema

Table 3.5: showing database schema

Table Name	Field	Description
BiosandFilter1	SampleNo (Integer, 50)	Sample Number field (Auto-increment integer number)
	SampleDate (Date)	Sample Date field
	FilterNo (char, 50)	Filter Number
	FilterType (char, 255)	Filter Type
	SampleSource (char, 255)	Sample Source
	TurbidityRW (char, 255)	Turbidity Raw Water
	TurbidityFW (char, 255)	Turbidity Filtered Water
	TurbiditySP (char, 255)	Turbidity Sphere Standard
	FlowVol (decimal)	Filter Flow Volume
	FlowDuration (decimal)	Filter Flow Duration
	ColiformCountRW (char, 255)	Coliform Count Raw Water

	ColiformCountFWO (char, 255)	Coliform Count Filtered Water Overnight
	ColiformCountFWS (char, 255)	Coliform Count Filtered Water Same DAY
BiosandFilter2	SampleNo (Integer, 50)	Sample Number field (Auto-increment integer number)
	SampleDate (Date)	Sample Date field
	FilterNo (char, 50)	Filter Number
	FilterType (char, 255)	Filter Type
	SampleSource (char, 255)	Sample Source
	TurbidityRW (char, 255)	Turbidity Raw Water
	TurbidityFW (char, 255)	Turbidity Filtered Water
	TurbiditySP (char, 255)	Turbidity Sphere Standard
	FlowVol (decimal)	Filter Flow Volume
	FlowDuration (decimal)	Filter Flow Duration
	ColiformCountRW (char, 255)	Coliform Count Raw Water
	ColiformCountFWO (char, 255)	Coliform Count Filtered Water Overnight

	ColiformCountFWS (char, 255)	Coliform Count Filtered Water Same DAY
BiosandFilter3	SampleNo (Integer, 50)	Sample Number field (Auto-increment integer number)
	SampleDate (Date)	Sample Date field
	FilterNo (char, 50)	Filter Number
	FilterType (char, 255)	Filter Type
	SampleSource (char, 255)	Sample Source
	TurbidityRW (char, 255)	Turbidity Raw Water
	TurbidityFW (char, 255)	Turbidity Filtered Water
	TurbiditySP (char, 255)	Turbidity Sphere Standard
	FlowVol (decimal)	Filter Flow Volume
	FlowDuration (decimal)	Filter Flow Duration
	ColiformCountRW (char, 255)	Coliform Count Raw Water
	ColiformCountFWO (char, 255)	Coliform Count Filtered Water Overnight
	ColiformCountFWS (char, 255)	Coliform Count Filtered Water Same DAY

The database schema for the other 6 tables for **CeramicFilter1**, **CeramicFilter2**, **CeramicFilter3**, **OtherFilter1**, **OtherFilter2** and **OtherFilter3** are similar to **BiosandFilter1**, **BiosandFilter2** and **BiosandFilter3** respectively.

The schema for the Filters table has only one field as below .

Table Name	**Field**	**Description**
Filters	FilterType	Filter Type

3.3.4. Program Testing

The next step in the process was to test the code. Testing was accomplished by running the program and manually checking the results. All possibilities and extreme data (invalid data, limit values, empty/null values) were tested and the program performed as anticipated. White box testing, commonly called glass box testing was applied; it refers to testing done by the person who wrote the program code.

3.3.5. Maintenance

After the code had been thoroughly tested and found to deliver as per expectation, Maintenance which involves updating and editing the code in order to make it more efficient and customized to diverse applications will also include correction of "bugs", which are errors in code that may have not recognized during testing.

3.4. Biosand filter and Filtron filter comparision

While addressing the second objective, the following code (part of the code) was written to compare the performance of these two filters;

```
/*
* CompareFaecalCountChart.cs
* This is the Class for analyzing Faecal Pollution per technology per filter
* The Class Loads the relevant from the tables in database and displays it in a
* Chart for further analysis
**********************************************/

using System;
using System.Collections;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Data.OleDb;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Windows.Forms;
using System.Windows.Forms.DataVisualization.Charting;

namespace HFTEvalApplication
{
    public partial class CompareFaecalCountChart : Form
    {
        public OleDbConnection conn;
        public OleDbDataAdapter adapter1;
        public OleDbDataAdapter adapter2;
        public OleDbDataAdapter adapter3;
        public DataSet data1;
        public DataSet data2;
        public DataSet data3;

        string strFilterType;
        int numberFilters;

        public CompareFaecalCountChart()
        {
            InitializeComponent();
        }

        private void CompareFaecalCountChart_Load(object sender, EventArgs e)
        {
            ChartDataBind();

        }

        private void ChartDataBind()
        {
            string strFilterType = this.Text;
            //string strHFT = "HFT Evaluation System:";

            if (this.tabControl1.SelectedTab == tabPage1)
            {
                try
                {
                    OleDbConnection conn = new OleDbConnection();

                    // Create the connection string
                    conn.ConnectionString =
Properties.Settings.Default.HFTDatabaseConnectionString;

                    conn.Open();

                    string strQueryString = "SELECT * FROM BiosandFilter1";
```

The recorded data was fed into the C# program developed above to display the output..

3.5. Code Implementation

The program provides an interactive Graphical User interface for communicating with the user. The features and effects have been enhanced and since it is a windows application it is supported in a personal stand alone computer installed with Microsoft visual C# express. However the program can be converted into a web based service in the future to extend accessibility.

Results and Discussions

HFT Evaluation System™ is a software solution for evaluating the effectiveness of household water filters. The system allows the user to input data, view trend changes and analyze turbidity and faecal contamination of water samples run through different filters.

This system is primarily designed to analyze data samples for three types of filters but may be scaled upwards in future to analyze data samples for more filter types. It is worth noting that the system can handle three different filters for each technology, analyze data for each filter and even compare the performance of each filter against the other filters.

Once the solution is run, the system can perform the following operations;

- Enter Sample data
- Filter performance analysis
- Reports
- Exit the program

Enter Sample Data:

It prompts a user to select the number of filters to consider in the analysis. Depending on the number so selected the program displays data form which allows data importation with options for editing and saving as shown below:

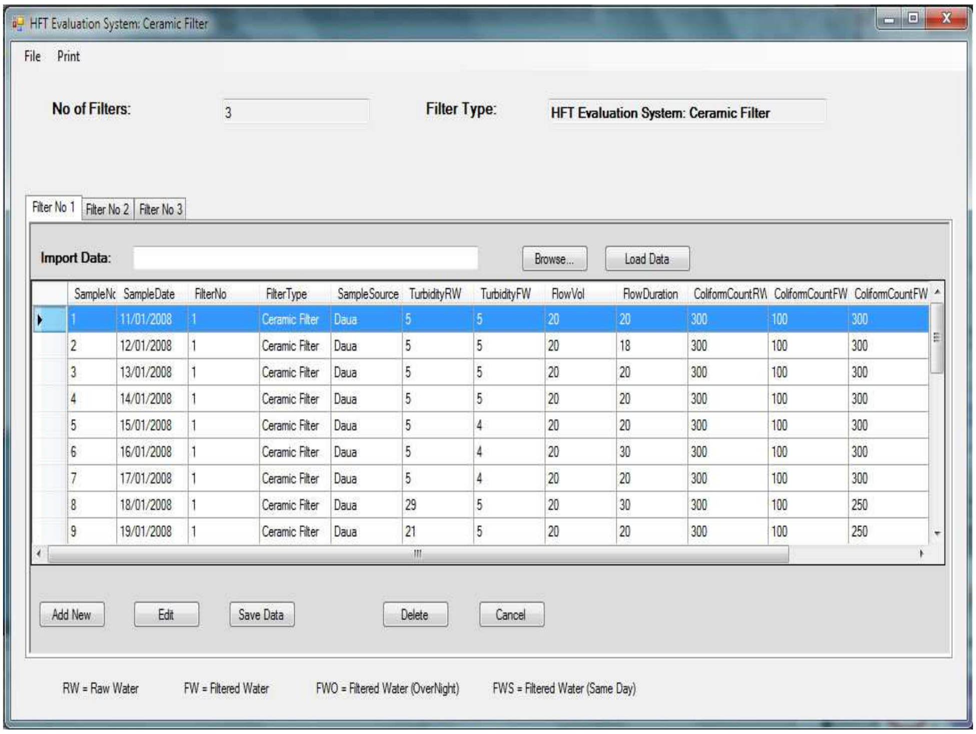

Table 4.1: program dialogue box for data manipulation

Filter performance

Under the option three types of analyses are possible, viz;

- Flow rate
- Turbidity and,
- Facael Pollution

Flow Rate

Analysis of this parameter is achieved through graphical representations and logic manipulation to output useful statements for decision making. The displays afford easy, quick and effective way in comparing performance based on flow rate. The program is useful in determining whether a specific filter can meet a household water requirement according to recommended international standards of WHO, SPHERE as well as local.

Here is how results for selected biosand filters are represented.

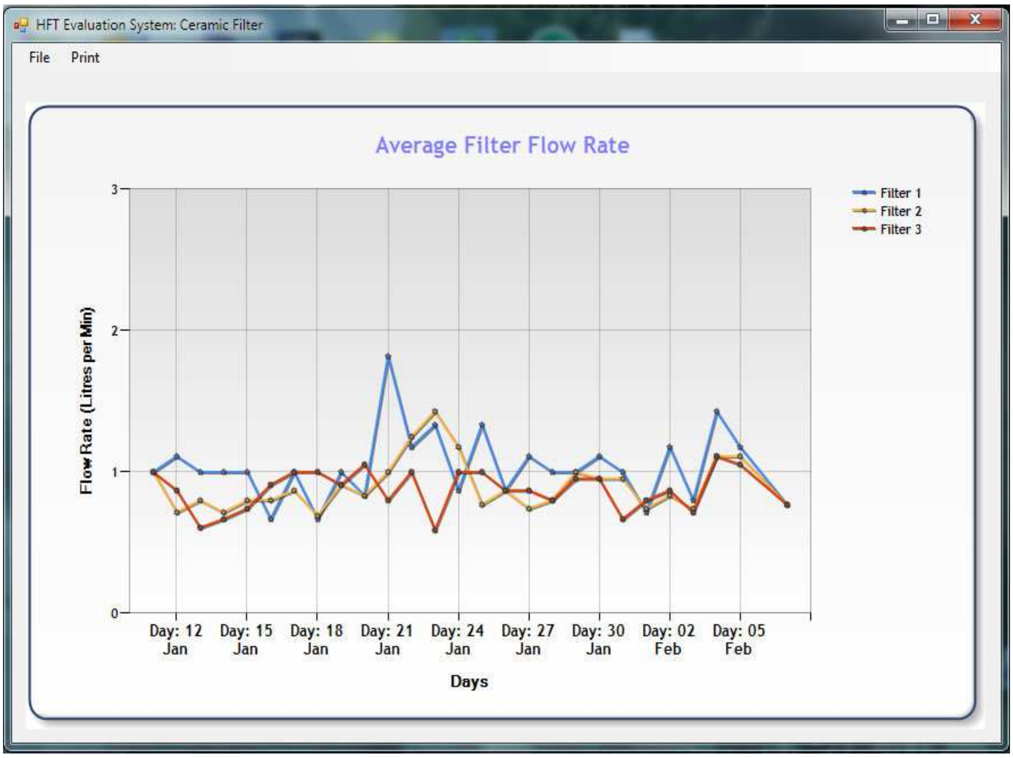

Figure 4.1: showing average filter flow rate for three biosand filters

On average a biosand can filter point nine litres per every minute when water is run through it. This is significant in the sense that with a drinking water requirement per capita per day of nine liters; the filter can meet requirements of six member family while in use for one hour.

Turbidity

Like flow rate, turbidity of each filter is plotted graphically by the program. Of interest is the fact that turbidity projections for each filter can be compared simply by examining the line graphs. Further comparison and in particular against SPHERE standard is also made possible through this study parameter. The system also evaluates the extents of turbidity reduction thereby posting a string statement to indicate whether the filter can be recommended or not for use at household level in relation to turbidity reduction as displayed next.

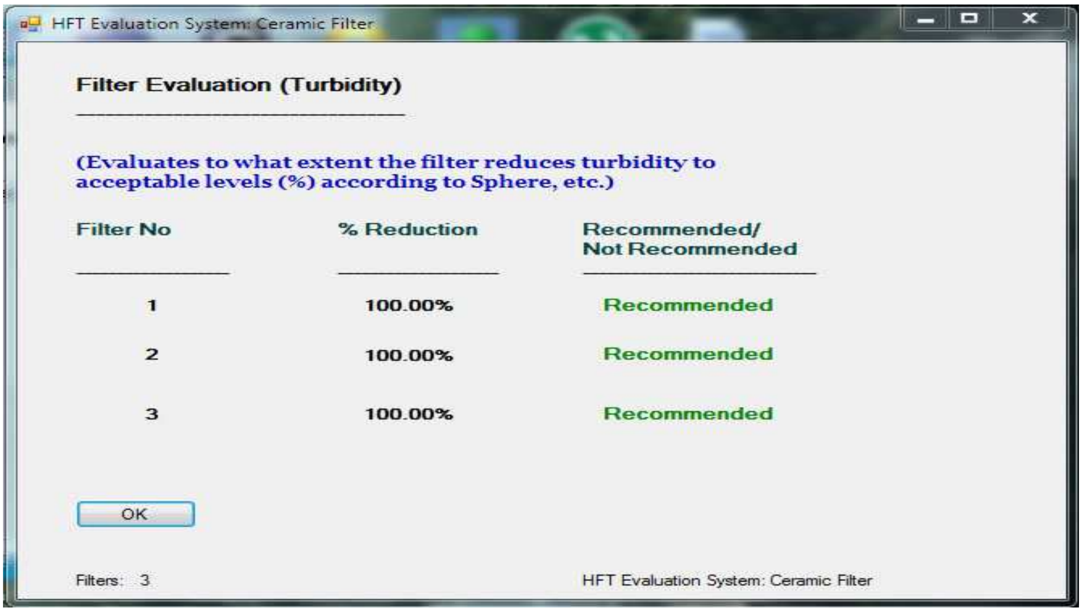

Figure 4.2: displays turbidity reduction in relation to international standards

Faecal Pollution

Faecal contamination general trends for different filters are observed through this analysis. Under this option the program determines the percentages of reduction in faecal pollution levels and goes a step further in comparing performance against set standards thus enabling determination of filter ability to produce safe drinking water. Different results of the analysis are shown below.

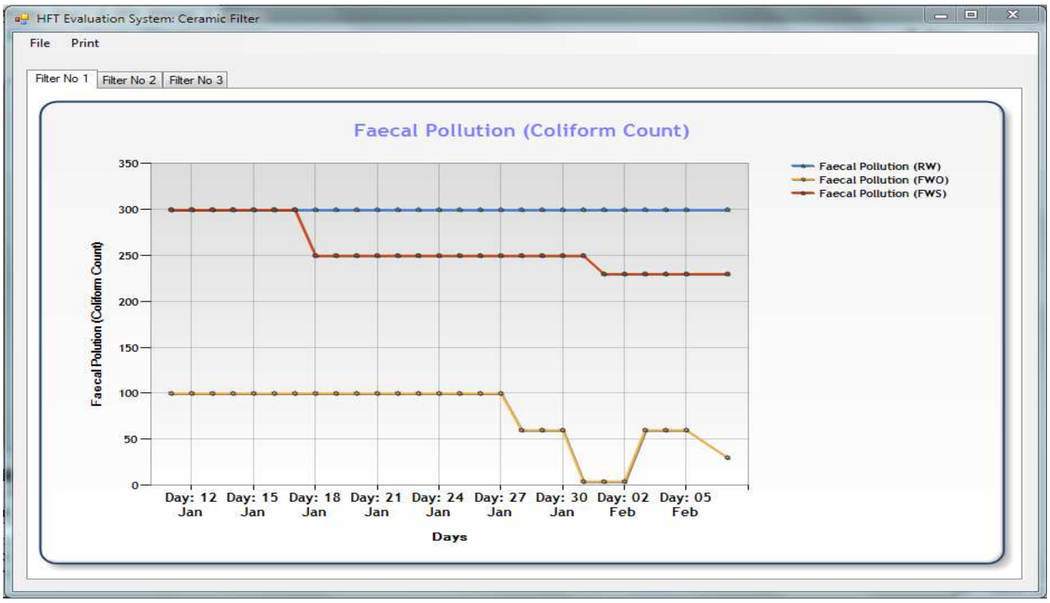

Figure 4.3: comparing the faecal contamination levels for raw and filtered water

The HFT Evaluation System™ software solution provides a platform where the biosand and ceramic filters are compared based on flow rate, turbidity and faecal pollution performances when subjected to similar conditions as indicated in figures 4.4, 4.5 and 4.6 respectively.

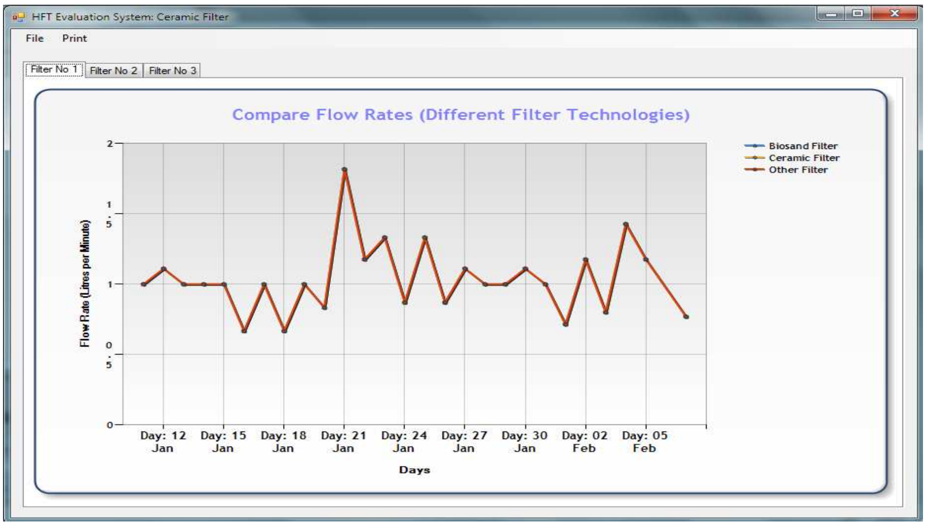

Figure 4.4: flow rate comparisons between biosand and ceramic filters

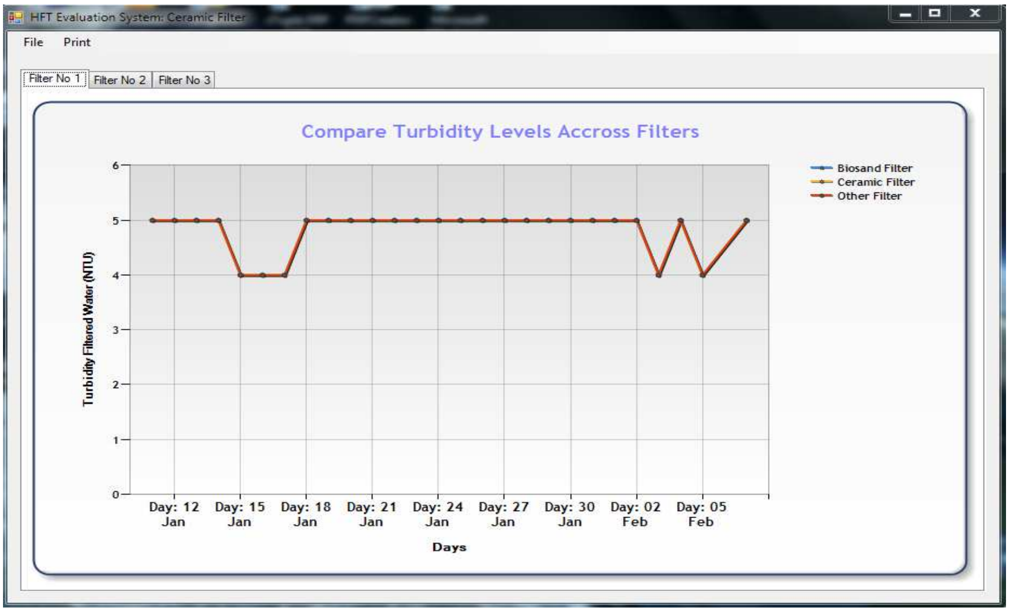

Figure 4.5: turbidity reduction comparison between biosand and ceramic filters

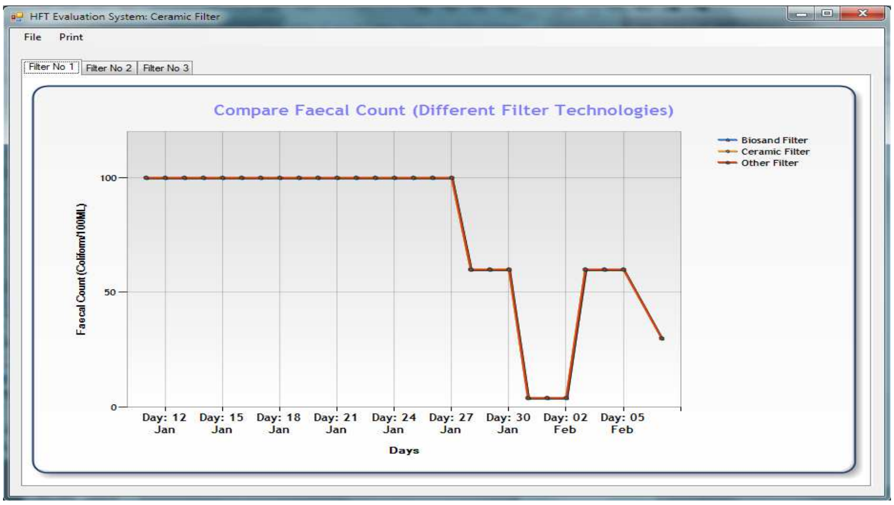

Figure 4.6: biosand and ceramic filters faecal pollution reduction comparison

Conclusion

Writing a program code in C sharp has been both exciting and challenging however, objectives of the thesis were met successfully since the HFT Evaluation system developed has provided a desired solution and thus the application can be used to evaluate performance of household water treatment and safe storage technologies based on flow rate, turbidity and faecal pollution parameters.

The program compares filters within the same technology and for different technologies. Such a feature is advantageous in the sense that not only can the best technology be selected but also general trends are easily established within specific household filtration technologies. For instance, comparisons between biosand filter and ceramic filter show that the later is best in faecal contamination reduction while the former gives the highest rates of filter flow though; both achieve permissible turbidity considered fit for human drinking.

In the past many nongovernmental organizations have seen a huge amount of money go down the drains in piloting new household water treatment technologies without prior means for evaluating and even simulating the most apt ones in order to achieve best results hence not meeting program and project's objectives.

Development of the HFT Evaluation System™ software will greatly increase the efficiency with which actors in the water, sanitation and hygiene practice perform their duties in respect to selection of appropriate household filtration treatment technologies. This can be attributed to the successful development of HFT Evaluation system which simplifies decision making process while maintaining the high integrity in data manipulation.

It is hoped that water and sanitation actors including nongovernmental organizations, different governmental entities, united nation children education fund and others will find HFT Evaluation System™ important in propagating household water treatment and safe storage technologies towards achievement of environmental sustainability millennium development goal and in particular "halve, by 2015, the proportion of the world without sustainable access to safe drinking water and basic sanitation".

Recommendation

The system is designed to display tabular and graphical representation of data while analyzing filter flow rates, turbidity levels and faecal pollution parameters. It does so for three filters of each technology. However, may be scaled upwards in future to analyze data samples for more filter types.

The features and effects have been enhanced and since it is a windows application it is supported in a personal stand alone computer installed with Microsoft visual C# express. However it is recommended that in future the program be converted into a web based service to extend scope of user accessibility and consequent accrued benefits.

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Appendices

Table 3.1: water testing results for filter BSF1

Date	**Turbidity, NTU**		**Filter Time**			**Coliform Count, No/100ml**		
	Raw Water	Filtered Water	Start	Stop	Duration	Raw Water	Filtered Water(OvN)	Filtered Water(SD)
11/1/2008	5	5	8:00	8:20	20			
12/1/2008	5	5	5:00	5:18	18	>200	<200	>200
13/01/08	5	5	5:20	5:40	20			
14/01/08	5	5	5:00	5:20	20			
15/01/08	5	<5	6:00	6:25	20			
16/01/08	5	<5	5:40	6:10	30			
17/01/08	5	<5	6:05	6:25	20			
18/01/08	<30	5	4:00	4:30	30			
19/01/08	>20	5	6:10	6:30	20			
20/01/08	20	5	8:56	9:20	24			
21/01/08	10	5	5:30	5:41	11			
22/01/08	10	5	5:25	5:42	17			
23/01/08	10	5	3:50	4:05	15			

24/01/08	10	5	3:49	4:12	23			
25/01/08	10	5	3:50	4:05	15			
26/01/08	10	5	3:49	3:12	23			
27/01/08	20	5	3:17	3:35	18			
28/01/08	<20	5	9:45	10:05	20	>200	60	>200
29/01/08	<20	5	5:30	5:50	20			
30/01/08	<20	5	5:30	5:48	18			
31/01/08	20	5	2:28	2:48	20	>200	4	>200
1/2/2008	20	5	4:32	5:00	28			
2/2/2008	10	5	5:56	6:13	17			
3/2/2008	10	<5	7:39	8:04	25	>200	60	>200
4/2/2008	10	5	5:16	5:30	14			
5/2/2008	10	<5	9:40	9:57	17			
7/2/2008	10	5	2:13	2:39	26	>200	30	>200
8/2/2008	10	5	10:42	11:06	24			
9/2/2008			3:18	3:34	16			
10/2/2008	10	5	2:47	3:06	19			
11/2/2008	10	5	3:42	4:00	18			
12/2/2008	10	<5	3:16	3:34	18	>200	20	>200

13/2/2008	10	5	4:30	4:51	21			
14/2/2008	10	<5	11:53	12:43	20	>200	10	>200

Table 3.2: water testing results for filter BSF2

Date	**Turbidity, NTU**		**Filter Time**			**Coliform Count, No/100ml**		
	Raw Water	Filtered Water	Start	Stop	Duration	Raw Water	Filtered Water(OvN)	Filtered Water(SD)
11/1/2008	5	5	8:00	8:20	20			
12/1/2008	5	<5	5:04	5:32	28			
13/01/08	5	<5	5:25	5:50	25			
14/01/08	5	<5	5:04	5:32	28			
15/01/08	5	5	6:10	6:35	25			
16/01/08	5	5	3:55	4:20	25			
17/01/08	5	<5	4:05	4:28	23			
18/01/08	30	5	4:15	4:44	29			
19/01/08	5	5	6:20	6:42	22			
20/01/08	>20	5	8:57	9:21	24			
21/01/08	20	5	4:55	5:15	20			
22/01/08	<20	5	5:40	5:56	16			

13/01/08	<20	<5	5:20	5:34	14			
24/01/08	20	5	3:56	4:13	17			
25/01/08	<30	5	3:50	4:17	26			
26/01/08	20	<5	5:18	5:41	23			
27/01/08	>10	5	9:47	10:14	27	>200	30	>200
28/01/08	>10	<5	5:39	6:04	25			
29/01/08	<20	5	5:32	5:52	20			
30/01/08	20	5	2:29	2:50	21	>200	>200	>200
31/01/08	20	5	2:29	2:50	21			
1/2/2008	20	5	4:33	5:00	27			
2/2/2008	30	5	6:00	6:24	24			
3/2/2008	10	<5	7;40	8;07	27	>200	>100	>200
4/2/2008	20	5	5;15	5;33	18			
5/2/2008	10	5	9;41	9;59	18			
7/2/2008	10	5	2;14	2;40	26	>200	10	>200
8/2/2007	10	5	10;43	11;07	24			
9/2/2008			4;36	5;01	25			
10/2/2008	10	5	2;48	3;13	25			
11/2/2008	10	<5	3;43	4;07	25			

12/2/2008	10	5	3;17	3;42	25	>200	20	>200
13/2/2008	10	<5	4;31	4;56	25			
14/2/2008	10	5	11;52	12;22	28	>200	10	>200

Table 3.3: water testing results for filter BSF3

Date	**Turbidity, NTU**		**Filter Time**			**Coliform Count, No/100ml**		
	Raw Water	Filtered Water	Start	Stop	Duration	Raw Water	Filtered Water(OvN)	Filtered Water(SD)
11/1/2008	5	5	8:21	8:41	20			
12/1/2008	5	5	5:07	5:30	23	>200	<200	>200
13/01/08	5	5	5:27	6:00	33			
14/01/08	5	<5	5:00	5:30	30			
15/01/08	5	<5	6:17	6:44	27			
16/01/08	30	5	3:56	4:18	22			
17/01/08	5	5	4:01	4:21	20			
18/01/08	30	5	3:56	4:18	20			
19/01/08	20	5	4:11	4:34	22			
20/01/08	10	5	6:15	6:34	19			
21/01/08	>20	5	8:58	9:23	25			

22/01/08	20	5	4:56	5:16	20			
23/01/08	<30	5	5:24	5:57	34			
24/01/08	10	<5	5:00	5:20	20			
25/01/08	10	<5						
26/01/08	>20	5	4:06	4:29	23			
27/01/08	<30	5	3:19	3:42	23			
28/01/08	<20	5	9:48	10:13	25	>200	>100	>200
29/01/08	20	5	5:33	5:54	21			
30/01/08	20	<5	2:30	2:51	21			
31/01/08	20	5	3:30	4:00	30	>200	0	>200
1/2/2008	20	5	4:35	4:50	25			
2/2/2008	30	5	5:58	6:21	23			
3/2/2008	10	<5	7;41	8;09	28	>200	10	>200
4/2/2008	20	5	5;12	5;30	18			
5/2/2008	10	5	9;42	10;01	19			
7/2/2007	10	5	2;15	2;41	26	>200	10	<200
8/2/2008	10	5	10;44	11;08	24			
10/2/2008	10	<5	2;49	3;09	20			
11/2/2008	<10	<5	3;44	4;04	20			

12/2/2008	<10	<5	3;18	3;38	20	>200	0	>200
13/2/2008	<10	<5	4;32	4;52	20			
14/2/2008	<10	<5	11;50	12;15	24	>200	0	<200