ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAIT)

SCHOOL OF GRADUATE STUDIES

CHEMICAL ENGINEERING DEPARTMENT

ENVIRONMENTAL ENGINEERING STREAM

OPTIMIZING THE PROCESS CONDITIONS OF SOLAR WATER DISINFECTION FOR THE RURAL-AREA

(Case study in Benishangul- Gumuz Region, Guba Woreda, Ethiopia)

By: Desssalegn Abebe

A Thesis Submitted To the School Of Graduate Studies of Addis Ababa University on Partial Fulfillment of the Requirement for Master of Science in Environmental Engineering

Advisor: Dr.Tassisa Kaba

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Acronyms

AAU	Addis Ababa University
BGRWME	Benishangul Gumuz Regional Water, Mine And Energy Bureau
BSF	Biosand filter
BGR	Benishangul Gumuz Region
CFU	Colony forming unit
EWRMP	Ethiopian water resource management policy
Hrs	Hours
HWTS	House hold water treatment system
kwh/m^2	kilowatt-hour per meters square
NTU	Nephelometric Turbidity Unit
PET	polyethylene terphtalate
POU	point of use
SDWT	Solar drinking water treatment
SODIS	solar drinking water disinfection
ssh	sunshine hour
Temp	Temperature
UNICEF	United Nations International Children Fund
UV	ultraviolet
WHO	World Health Organization

Abstract

In this paper one alternative house hold based solar water treatment (SDWT) technology is dealt with taking Guba Woreda as study area. It is intended in finding local solutions for constraint that are found to affect the sustainability of the process.

Water sources that are in consumption by the community were characterized for their turbidity and microbial quality during the time the study was conducted, ending with turbidity of <50NTU for most water sources and 2-95 FCU microbial load. In the study in general, it has been tried to contextualize the technology for the area. The different factors affecting the technology have been investigated in combination giving rise to an optimum factorial combination of 2L container size with turbidity of <90NTU requiring 4:45 exposure time yielding a response of zero faecal coli form unit.

The simple pretreatment unit designed is with the material found in the hands of the society, including the coagulant-flocculants (i.e. Moringa, a miracle tree). This has resulted in turbidity removal of 70-95%.

Finally a simple batch mode operating system has been developed that may simplify the work load of using bottles separately. Therefore these all operations being in the hand and skill of the community, it can be inferred that the technology can be applied in the study area with minimum cost in a sustainable manner.

Key words: Rural community, unsafe water sources, Moringa, Water treatment, SDWT, clean water.

1. Introduction

1.1. Background

Water of sufficient quality & quantity is one of the basic necessities to human being. But this is far from being fulfilled especially in developing countries. Ethiopia is one of the wealthiest countries in the world with respect to water resources. On the contrary the access rate to drinking water and sanitation in Ethiopia is among the lowest in the world [1]. The regional distribution of water coverage according to the Ethiopian government's 2001 figures is quite low ranging from 16% in Aar to 70% in Addis Ababa. The national water coverage is 74% in urban areas, 23% in rural areas (where 83% of the population lives) and 31% average over the whole country.

Those without access to safe water depend on surface water sources such as unprotected springs, ponds, streams and rivers which, in most cases are located at great distances from their households (up to six hours in rural Ethiopia) where the burden highly rests on women and children. This fact holds true in most of rural areas found in Benishangul. Even in urban areas, where access to safe water is higher, the quality and quantity of water supply is far from being adequate [1].

In order to improve the living condition of the people, it is necessary to provide them ways towards safe and clean drinking water. Local, efficient & cost effective technologies at the house hold level are the basics. The technologies to be developed should actually resolve the aforementioned problems in a sustainable manner adding values to the efforts of women &children wasting their time and energy by fetching water from such unprotected sources.

The technologies to be devised should impose no harm on the environment. The cost they incur while application should be optimal so that it can be adopted in the rural societies where their income is lower.

Green technologies are of top priorities that fulfill the aforementioned criteria's now days. That is the reason why I am forced to conduct my thesis work on solar water treatment.

Ethiopia is the land of maximum insolation (lies within the tropics (3^0N to 18^0N latitude)). Every place in Ethiopia has overhead sun twice a year. Ethiopia is a country with 13 months of unused sunshine! Most parts of Ethiopia receive over 7 hours of bright sunshine daily, and in the south eastern, northern and north eastern lowlands, it reaches 10 to 12 hours duration(as is the case in Guba). Guba, the main focus of the study, found in Benishangul Gumuz region (09.17^0 - 12.06^0 North latitude and 34.10^0 - 37.04^0 East longitude) is characterized by higher temperature and sunshine hours as depicted in ANNEX 4. Therefore Ethiopia is the country where solar disinfection technology can be utilized with the most benefit i.e. implementing use of this green source for treating drinking water at house hold level can benefit many rural communities which are being heated by water born problems like diarrhea.

However there are bottle necks that have been observed hindering such an attempt. The first is the very poor infrastructure, the scattered settlement pattern, in most rural areas like the one under study, where about 92% of their population is in rural area [2].

The second is the place given to quality is quite low in relation to improving the coverage. But it should be emphasized that if worked extensively at least on awareness creation to sanitation and hygiene great improvement could be achieved.

The society are not even well encouraged to use chlorination at least, though has some side effect. And if good management is practiced, it is possible at least to maintain the quality of such sources. Ground water is believed to be of good quality microbiologically, but it is observed that they get contaminated even during the development process.

Thus it should be given credit to the lives taken away from such ignorance. And emphasis has to be given to quality aside quantity as it could at least be addressed by the society, at lower cost at house hold level. And it should be thought that societies are paying the cost at higher rate indirectly, through health posts as a result of water related diseases.

Therefore unless attention is given to the issue by any concerned bodies conducting researches on water treatment will remain wastage (of both time and money).

1.2. Statement of the Problem

Drinking water sources in major regions of Ethiopia are not safe. In particular in rural regions of the country like Benishangul, Afar, Somali, Gambella & the like the problem from access to safe drinking water is sever. In short it could be said access to safe drinking water is a dream like situation in these areas.

Specifically speaking in the region where this particular study emphasis, drinking water sources for the remote & sparsely distributed societies are: unprotected springs, ponds& rivers. The quality of which is poor particularly with respect to microbiological quality as evidenced by the regional water quality lab conducted on some sources (BGR water bureau).

Surprisingly the settlement pattern of the indigenous societies (particularly Gumuz people) is along the river basins particularly along Abbay basin at the border of Sudan which is their drinking water source.

Generally no one of the proved water treatment methods at house hold level is in use by the society (throughout the region). The infrastructural facilities being at the grass root level has worsened the problem further. The educational level of the society matters. The existing limited supply systems are not even treated regularly. Even there is high probability of the treated water being contaminated during the overall process (fetching, transportation & while consumption).

1.3. Objectives

General Objective

It is generally intended in providing microbiologically safe drinking water for societies living in remote, rural& hottest areas by developing appropriate & cost effective drinking water treatment technology that can easily be managed by the skill of the society, using locally available materials.

Specific Objectives

- Conducting on site experiments (Field tests).
- Optimizing the process conditions
- Designing a simple pretreatment unit.

1.4. Significance of the Study

So far no studies have been conducted regarding use of this resource for treating drinking water in Ethiopia. Thus the project is significant in the first place for awareness creation. It is also significant with respect to:

- Improving the health status of the community, especially the rural-poor which are forgotten.
- Introducing the community with a technology that they can handle with skill & material they have.
- Use of naturally sustainable resource with minimum cost (cost of bottles which is affordable by any class of society).
- Can serve as the starting frame for further investigation on similar or associated issues.

2. Literature Review

2.1. General Water Quality Situation

Current estimates of the number of people using microbiologically unsafe water (about 1.2 billion people drink contaminated water globally & about 4000 children dying off diarrhea cases are probably low [3]. 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 faecally contaminated and deliver microbiologically unsafe water as is evidenced by water quality data taken from the regional bureau of the study area. In some cities the water systems abstract unsafe water from unprotected or contaminated sources and deliver it to consumers with no or inadequate treatment (cases like river sand dams in areas of this research), yet these water systems are classified or categorized as improved and safe.

People now drinking unsafe household water also include those in rural as well as urban settings. Many rural dwellers lack indoor plumbing or nearby outdoor piped water from a safe supply (from wells, boreholes, protected or upland surface water sources, etc.). Often they have to travel considerable distances to reach any water source, regardless of quality, for collection and household use, which holds good in areas of my case study [4].

Microbial contamination of collected and stored household water is caused not only by the collection and use of fecally contaminated water that was not safe to begin with but also by contamination of initially microbiologically safe water after its collection and storage. Factors contributing to this problem are unsanitary and inadequately protected (open, uncovered or poorly covered) water collection and storage containers, the use of unsanitary methods to dispense water from household storage vessels, including fecally contaminated hands and dippers, lack of protection against contamination introduced by vectors (flies, cockroaches, rodents, etc.) and inadequate cleaning of vessels to prevent biofilm formation and accumulation of sediments and pathogens.

Improving and protecting the microbial quality and reducing the infectious disease risks to consumers of collected water stored in households requires alternative or interim strategies and approaches that can be implemented effectively, quickly and affordably. As will be described in this report, technically feasible, effective, socio-culturally acceptable and affordable methods for treatment and storage of household water to improve microbial quality and reduce waterborne disease risks are now available.

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 stored water and reducing the risks of diarrheal disease and death in populations of all ages in the developed and developing world. A variety of physical and chemical treatment methods to improve the microbial quality of water are available and many have been tested and implemented to varying extents in a variety of settings and for a diverse range of populations. Many different water collection and storage systems and strategies have been developed, described and evaluated on the basis of various criteria for household and community use. Some of them have been tested under controlled conditions in the laboratory and implemented in field to evaluate their ability to produce drinking water of acceptable microbiological quality and to maintain this quality during storage and use. Some of them also have been evaluated in the field for their ability to reduce diarrheal and other waterborne diseases among users. Because of the importance of education, socio-cultural acceptance, changing people's beliefs and behaviors, achieving sustainability and affordability in the provision of safe water, some of the most promising household water treatment and storage systems and their implementation strategies include or are accompanied by efforts to address these considerations [4].

The most important criteria's for comparing different treatment options are : effectiveness in improving and maintaining microbial water quality, reducing waterborne infectious disease, technical difficulty or simplicity, accessibility, cost, socio-cultural acceptability, sustainability and potential for dissemination. The focus of this critical review is on technologies and systems to protect water during storage, collection and use, in improving the microbial quality of the collected water, and thereby reduce pathogen exposure and risks of diarrheal and other waterborne diseases. This is not intended to be a comprehensive review of water treatment methods that reduce and thereby minimize exposures to various chemical contaminants. While toxic chemicals in drinking water are an important public health concern, it has been repeatedly demonstrated and generally accepted that the most important and immediate risks to human health by using contaminated drinking water are those from enteric microbes of fecal origin or other sources. Hence, the focus herein is on strategies and systems for protection and improvement of the microbiological quality of household water and prevention and control of waterborne microbial diseases. However, some of the technologies that reduce waterborne microbes also reduce certain toxic chemicals, such as arsenic [4].

The situation here in Ethiopia with respect to water quality is the worst. This is because no attempt is being made with respect to quality rather than running for the water supply coverage alone. But this all efforts will have meaning provided that this all sources are provided to the community fulfilling the quality requirements by WHO or national guideline. And it is easy to imagine what the degree of the problem will be, in areas where no water supply systems do exist. That is why it is initiated in devising an appropriate treatment method at household level that could be applied in areas where the society has never seen developed water schemes.

2.2. Water Treatment

Water treatment describes those processes used to make water more acceptable for a desired end-use. These can include use as drinking water, industrial processes, medical, agricultural and many other uses. The goal of all water treatment process is to remove existing contaminants in the water, or reduce the concentration of such contaminants so the water becomes fit for its desired end-use. Appropriate technology options in water treatment include both community-scale and household-scale point-of-use (POU) designs.

When large community-wide water treatment and distribution systems are not available, people may treat water individually or for their families. There are several proved water disinfection options available for small-scale use. The most promising and accessible ones are filtration with ceramic filters, chlorination with storage in an improved vessel, solar disinfection in clear bottles by the combined action of UV radiation and heat, thermal disinfection (pasteurization) in opaque vessels with sunlight from solar cookers or reflectors and combination systems employing chemical coagulation-flocculation, sedimentation, filtration and chlorination. But their application in a particular area depends on reliability, constructability, ease of operation, simple maintenance and most important cost.

Water disinfection methods can broadly be divided into two categories. The first category is chemical disinfection. Chemical disinfection includes methods such as chlorination and iodine treatment. Chlorine is the most common method of drinking water treatment due to its effectiveness at inactivating several types of pathogens. Chlorinated water also retains a residual that further protects from recontamination after the water is treated [5].

However chemical costs, the training needed to calculate proper chemical dosages, the unpleasant odor and taste of the drinking water as well as the disinfection byproducts may render such options unavailable to low-income families. An additional disadvantage with all chemical treatment methods is that chemicals oxidize over time and therefore have limited shelf lives.

Physical treatment methods such as boiling water and UV treatment may also be used to treat drinking water. Boiling water is a simple process, but requires resources that may not be readily available. This is especially true for areas concerned with the effects of desertification and deforestation because boiling one liter of water requires approximately one kilogram of wood. The process is time consuming and boiling water has been found to impart a disagreeable taste [6, 7].

2.2.1. Point-of-Use Water Treatment

While it is important to increase access to improved water sources, the assumption that improved sources of water are of higher microbial quality does not necessarily hold true after the water has been transported and stored in the home. For example, there are opportunities between the water source and the household for the water to become re-contaminated through contact with unwashed hands, further perpetuating the cycle of poor quality drinking water. Household storage containers often allow for recontamination when water is removed using a cup through the opening at the top of the storage container, be it a traditional clay pot or a plastic bucket.

In an investigation of point-of-use water quality from both unimproved and improved sources, it has been showed that microbiological water quality, specifically fecal contamination, was found at the point of consumption in water from both types of sources. In 75.6% of samples from improved water sources, there were levels of fecal coliform that exceeded the recommendations, which is 0FCU/100ml set forth by WHO use during humanitarian crises and emergencies at the point-of-use [8].

These opportunities for re-contamination can be averted through modern water treatment methods of clarification, sedimentation, and disinfection with centralized, piped water systems. With current trends, these systems are unlikely to be disseminated throughout much of the developing world for some time. There is a pressing need to bridge the gap between water that is safe at the source and water that is safe at the point of consumption, whether the point of consumption is at home or away from home. These efforts may primarily benefit those who do not have access to improved water sources. There may also be a benefit to people who have access to an improved water source but face a potential point- of-use health risk during water transportation or storage.

In a paper outlining household water treatment technologies, three broad areas of water quality- physical, chemical and microbiological- that can be improved by household water treatment technologies have been described. Physical removal technologies include ceramic and biosand filters, cloth filters, and coagulation/flocculation technologies. Boiling, solar disinfection (SODIS), chlorination, and UV irradiation with lamps are examples of technologies that improve the microbiological quality of the water. Improving the chemical water quality of source waters may require special measures at the household level, but can be achieved with charcoal or hybrid adsorption with carbon. There are also technologies that combine multiple methods to achieve improved water quality, for example, partnering coagulation and flocculation with a disinfection technology such as chlorination. Finally, safe storage containers should be designed using a standard size storage vessel, with a narrow mouth or opening with a lid and an easily accessible tap to dispense the water [9].

To demonstrate the ability of HWTS technologies to improve human health, several meta-analyses have been conducted to examine the variety of empirical evidence from the field [10].

Interventions aimed at improving water quality, such as household water treatment and safe storage (HWTS) technologies, have been shown to reduce diarrheal disease on average by 39% [10]. A more recent meta-analysis, conducted to assess the effectiveness of interventions that improve water quality has concluded that point-of-use interventions are more effective at reducing diarrhea in all age groups than interventions that improve water quality at the source [11]. Point-of-use treatment interventions have been shown to significantly reduce diarrheal disease [12, 13, 14, 15, and 16]

The effectiveness of individual point-of-use technologies is assessed through meeting water quality targets for pathogen reduction. Currently, a highly effective technology will reduce more than 99% of the pathogens, a moderately effective technology reduces pathogens by between 90% and 99%, and a technology that has low effectiveness only reduces pathogens by less than 90% [17].

The advantage of point-of-use technologies is that they are low-cost and can be implemented relatively easily in low resource settings. Point-of-use interventions are often combined with education and behavior modification campaigns to increase knowledge of waterborne disease and the pathways by which people become sick [17]. There remain a variety of considerations that need to be analyzed when determining the ability of a particular HWTS technology to be successful, particularly: simplicity, accessibility, cost, socio-cultural acceptability, sustainability and potential for dissemination [18].

2.3. Solar Drinking Water Treatment (SDWT)

Solar water disinfection uses the sun's (solar) energy, which is an abundantly available and renewable resource, to kill pathogenic microorganisms that are present in raw water. It is a simple, low-cost and environmentally sustainable water treatment solution, particularly at the household level [18, 19]

The sun continuously emits large amounts of solar radiation, or energy. This solar radiation can be broken down into sub-sections of energy radiated at different wavelengths. The diagram below depicts this energy band:

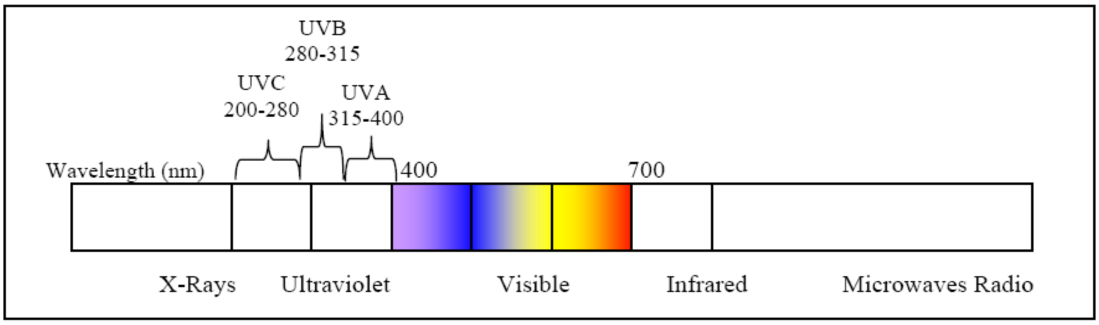

Figure 2.1: Radiation bands vs. wavelengths (Flores-Cervantes 2003)

The UV band can be broken down into UV-A, UV-B and UV-C. Most of the UV-B and UV-C light is absorbed by the ozone (O_3) layer in the earth's upper atmosphere and, hence, very little reaches the surface of the earth. UV-A rays, however, reach the earth's surface, and it is this range of light that has been shown to have a lethal effect on many of the pathogens present in water.

In addition, the infrared range of light is absorbed by water, which raises its temperature, thereby creating a "pasteurization" effect in the water. This pasteurization effect takes place at temperatures above 50^{o}C [20].

The Research on solar water disinfection was first initiated by Professor Aftim Acra at the American University of Beirut. It was for the sake of inexpensive method of disinfecting water for the addition of oral rehydration salts. The idea of Solar Water Disinfection was presented in 1984 in a booklet published by UNICEF, stating that the disinfection power is mainly from UV-A (320nm-400nm) & UV-B (400nm-490nm) contributing to some extent [6].

The development of SODIS in PET plastic bottles was studied in the early 1990's as a low-cost method for household water treatment. There is noted synergistic effect between the UV radiation and the increase in temperature created through exposure to solar energy. Inactivation of bacteria increases steadily as temperature increases from 20°C to 50°C and at temperatures above 50°C there is a significant increase in the inactivation of pathogens [20].

Further studies were conducted in the field to assess SODIS' application at the household level. A SDWT field study was conducted in Kenya and confirmed that synergistic effects between thermal energy and UV radiation occurred at temperatures greater than 45°C. In summary according to the study by different scholars, two different water treatment processes using solar energy were used to improve the microbiological water quality. The first, UV-radiation was used for its bactericidal effect. The second, infrared radiation raising the water temperature (50-60^{o}c) is known as pasteurization. A synergy of these two effects occurs, as their combined effect is much greater than the sum of the single effects. This means that the mortality of the microorganisms increases when they are exposed to both temperature and UV-A (320-400nm) light at the same time. Which are high enough to extensively (about 99.9%) inactivate many enteric viruses, bacteria and parasites in about 1 hour to several hours. [6, 20,23]

The researchers also concluded that inactivation of E. coli from UV radiation occurred even with turbid water sources of as much as 200 NTU provided the source water achieved a temperature of more than 55°C [21]. This study was able to demonstrate that SDWT was an applicable, low-cost household water treatment method.

The birth of this novel technique of water purification led to extensive research being carried out by the Swiss Federal Institute for Environmental Science and Technology (EAWAG) in collaboration with EAWAG's Department of Water and Sanitation in Developing Countries (SANDEC), from 1991 onwards. Several field and laboratory tests have been conducted by these two departments, which has led to the adoption of solar water disinfection as an effective purification solution in several countries [18]. Numerous other organizations and universities have also conducted solar disinfection studies [22, 23, 24, 25], work at the Massachusetts Institute of Technology.

2.3.1. Disinfection Mechanism

There are two main forms of disinfection that are caused by exposure of water to solar radiation. Inactivation of pathogens is caused by:

A. UV-A Radiation:

i). Direct alteration and mutation of pathogen cell deoxyribonucleic acid (DNA)

This primary disinfection process is due to the UV-A radiation, which directly affects the DNA structure of several of pathogens found in water. The radiation causes cells to mutate which ultimately results in cellular death. Any repair mechanism that the cells may have is overpowered at a threshold of $500W/m^2$ total solar radiation (radiation emitted by all spectrums of light.), applied for approximately 6 hours [18].

It should be pointed out that solar disinfection does not sterilize the water. Organisms that are not harmful to human health, algae for example, may still remain in the water [18].

ii). Indirect breakdown of pathogen cells due to the photo-oxidative effect

UV-A radiation can lead to the formation of reactive oxygen free radicals and hydrogen peroxides if there is sufficient dissolved oxygen (DO) in the water [26]. These radicals then oxidize cellular components of the pathogens, such as enzymes, nucleic acids and membrane lipids, which kills the microorganisms [27]. Although this process is secondary to the direct destruction of the pathogens by UV-A, it will nevertheless augment the disinfection process. Therefore, the presence of dissolved oxygen plays an important role in destroying the microorganisms.

B. Infrared Radiation

i). High temperatures (>50^oC) eliminates some sensitive microorganisms

Infrared radiation is absorbed by water, causing the water to heat up. Heating water to between 50^oC and 60^oC for one hour has the same effect as boiling the water, which would kill 99.9% of microorganisms [29]. Thus, the temperature of water plays a large role in increasing the rate of disinfection.

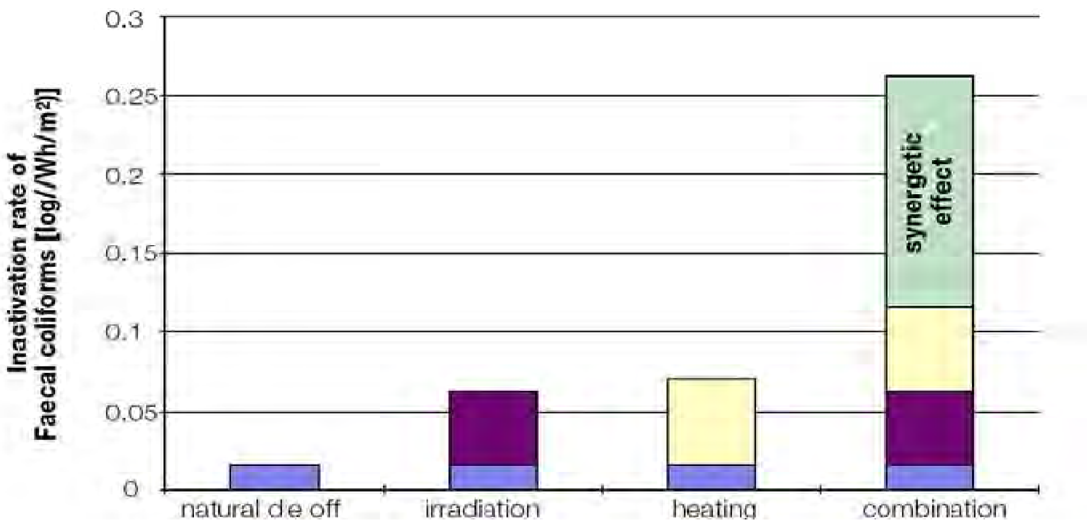

Figure 2.2: Combined effect of UV-A and thermal radiation on solar disinfection [19]

To explicate the effect of temperature on the disinfection process, EAWAG states that at a temperature of 30^0C, 6 hours of mid-latitude midday sunshine (radiation fluence of 555W.hr/m2 in the 350-450nm UV-A wavelength spectrum ≡ 3000W.hr/m2 in the entire wavelength spectrum) is required to achieve a 3-log reduction of harmful bacteria (faecal coliforms). At a temperature of 50^0C, however, this reduction is seen at an equivalent exposure time of just 1 hour (or 140W.hr/m2 of UV-A radiation for 6 hours) [18].

2.3.2. Indicator Organisms and Pathogens

SODIS efficacy is usually established through the inactivation of indicator organisms. They are the most commonly used gauges of SDWT success. A person discharges billions of organisms per day and most of the pathogenic fraction of these organisms is difficult to isolate and identify. Consequently, the presence of easily identifiable organisms is used to suggest the existence of pathogenic ones [30].

- ♣ Used for all types of water
- ♣ Present whenever enteric pathogens are present

- ♣ Should have a reasonably longer survival rate than pathogens
- ♣ Should not grow in water
- ♣ Should be a member of the micro-flora of warm-blooded animals
- ♣ Testing method should be easy to perform
- ♣ Density should allude to extent of fecal pollution

Unfortunately, no single group of organism meets all of the above criteria. Consequently, multiple indicator organism groups are often used. The two most common ones are total and fecal coli form.

To help eliminate possible false positives, coliform of only fecal origin can be used. These organisms consist of the Escherichia and Klebsiella genera. These coliforms can ferment lactose to produce both acid and gas at 44.5 ° C within 24 hours [30]. It has been suggested that E. coli be used as an indicator organism as it can readily be distinguished from other members of the coliform group. However, E. coli cannot be differentiated between human and animal origin. Despite these limitations, fecal coliform bacteria have proven invaluable in assessing drinking water quality.

2.3.3. Possible Health Risks Associated With the Process

Concerns about health risks related to SDWT are based on the suspicion that toxic substances could migrate from the PET bottle into the drinking water. Particularly, fears were fuelled by a press report published on 10 February 2003 in Source Weekly on the migration of organic compounds from reused PET bottles. This report was based on data taken from an investigation of organic chemicals trespassing to water in PET bottles reused for drinking water [31]. The authors identified several organic compounds in the water and observed increased migration rates with duration of reuse.

Migration of components of PET such as degradation products of the polymer, catalyst residues and other contaminants has been broadly and profoundly investigated in the past. Migrating compounds comprise production residues as well as hydrolysis and thermal degradation products of PET itself, additives, and, in the case of recycled or reused PET bottles, constituents of beverages previously contained in the bottles, such as flavour compounds.

The influence of environmental factors and storage time on the release of chemical substances from PET has been investigated in several studies. Photolytic formation of diffusing substances may also play a role. In sunlight exposure tests it has been shown that PET degradation products such as terephthalate monomers and dimers are primarily formed at the outer surface of the bottles [34].

Some researchers have also found di(2-ethylhexyl)phthalate (DEHP) and dibutylphthalate, in water stored in PET bottles for several months; however, these effect-based investigations revealed no mutagenic and carcinogenic components at critical concentrations [35,36]. From the literature on leaching of PET it becomes evident that time is a dominant factor governing the release of organic substances [31, 33, 34]. This was also observed in the case of antimony which is present in PET due to its use as polymerization catalyst [37]. A substantial migration of antimony from PET to water only takes place under conditions not typically occurring in the SDWT process, i.e. exposure at 80^{o}_C for several days [38].

2.3.4. Factors Affecting the Process

Previous studies have found that solar disinfection is affected by numerous variables. These variables include solar radiation intensity, water temperature, turbidity, water depth, topography, weather condition, and container selection.

2.3.4.1. SDWT Bottle Characteristics

PET (polyethylene terephthalate) bottles have emerged as the best SDWT container for several reasons. Plastic mineral water and soft drink bottles are gradually replacing glass. Plastic bottles are made of either PET or PVC (polyvinyl chloride). Both types of plastics contain UV stabilizers to protect the material from UV radiation and oxidation.

There is some concern, that some of these stabilizers may be a potential health risk. These additives are used much less in PET compared to PVC making PET the preferred SDWT material. PET is also a good transmitter of light in the UV and visible range. Simple comparison methods have been developed to determine whether a plastic material is PVC or PET. PVC has a distinct bluish gleam, which is especially noticeable around the edges [23]. Additionally, PVC smells caustic when burned, whereas PET smells sweet (SODIS Technical Notes). Most of the PET bottles produced in Ethiopia and used for packing of mineral water have notations named PET at bottom sides. And thus can easily be identified from PVC bottles.

2.3.4.2. Solar Intensity and Water Temperature

Weather condition of an area is decisive prior to adoption of one technology to an area. Experimental findings should pass the variability's in conditions. For that matter relevant data like sunshine hour, ambient temperature of the area (eight years data) were taken from Ethiopian national metrological agency. And as presented in ANNEX 4, there is sufficient sun shine hour greater than 6 hrs daily and extending to 10hrs a day in the dry seasons (January -April) including the boundary months November, December and May. And even during the rainy season there are days when the sunshine exceeds 6hrs a day.

The agro-ecology of the region is 75% arid and the study area, Guba is one of the arid woredas in the region. And the data studied on solar and wind potential of Ethiopia depicts a solar intensity of about 4.9kwh/m^2 per day, which is actually under controversy with the study by NASA and CESEN with a solar intensity value of about 5-6kwh/m^2 (in good agreement with some other studies per day [18]. With the lower estimate of 4.9kwh/ m^2 per day solar intensity during the dry seasons thus 7hrs of average daily sunshine hour gives solar radiations of about 700w/m^2. As shown in the following figure the daily sun shine hour of the study area during the dry seasons is greater than 7. Therefore one can state that the intensity in the area is quite greater than 700w/m^2.

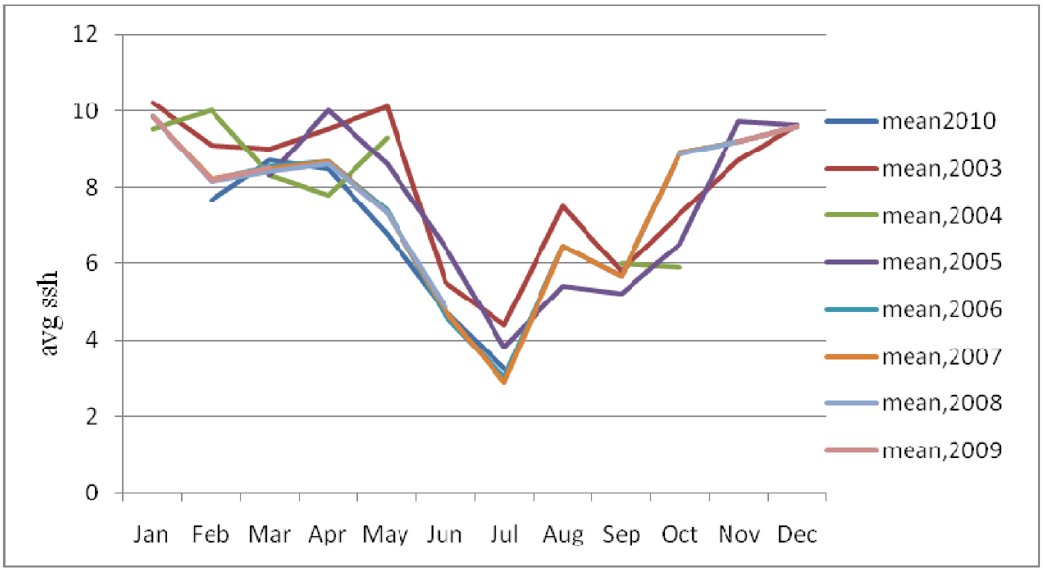

Figure2.3: Eight Years Average Monthly Sunshine Hour of Mankush

Similarly the noon ambient air temperature is quite high reaching to a maximum of 35-40 for most of the time as shown in the same ANNEX 4.

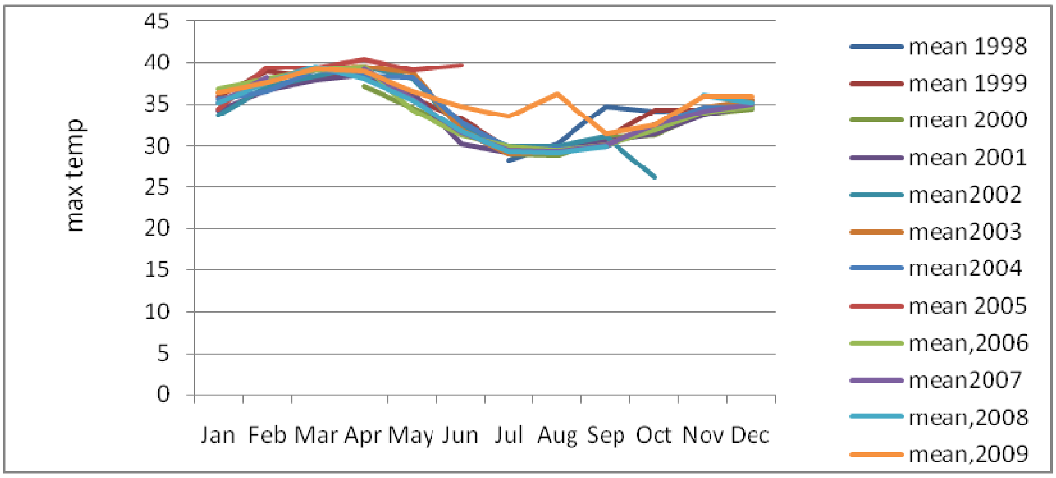

Figure 2.4: Mean of Monthly Temperature of Years 1998-2010

The other important condition is solar intensity. Studies State that the most important regions for SODIS are found within the region 35^0N-35^0S and, as Ethiopia is within this region she can be considered as the most favorable region. The variability of this intensity is considered important. But this variability decrease up on moving from the stated regions to equator. Ethiopia is a tropical country situated around the equator [18]. The national atlas of Ethiopia states that Ethiopia receives 6-7kwh/m^2 on average for 6-7 hours a day for most parts of the country particularly the peripheral areas, corresponding to 1-2kw/ m^2 solar intensity. This is much greater than the threshold intensity of 500W/m^2 required for SODIS [18]. The solar potential assessment of Ethiopia indicates that there is on average 4.9kwh/m^2 solar energy in Ethiopia which is actually less by 38% to the one studied by NASA and CESEN and their finding at regional level is a bit higher than this . But it should be noted that this is the average value of those all climatic zones: Dega, Weina Dega and Bereha. It is also the average value of all seasons including the rainy seasons. It also incorporates the two extreme daily hours 6am-9am and 4pm-6pm which are the lower intensity extremes even during sunny days [17]. The time of interest for this type of study is usually 9am-4pm daily, thus one can technically speak that the solar intensity of arid areas like the one under study will be much greater than what is presented by[17] . The solar intensity data at Woreda level studied by SWERA is shown in ANNEX 7.

Therefore,the suggestion that SODIS best applies under situations where the solar intensity threshold of 500w/m^2 is available and the water temprature can reach 30^oc (pretty enough to be maintained in areas where the ambient air temprature is >30^oc) is expected to best apply for the arid regions of the country like mankush.

2.3.4.3. Turbidity & Water Depth

Turbidity is the “decrease in the transparency of a solution due to the presence of suspended and some dissolved substances, which causes incident light to be scattered, reflected, and attenuated rather than transmitted in straight lines; the higher the intensity of the scattered or attenuated light, the higher the value of turbidity.

Turbidity can be measured in Nephelometric Turbidity Units (NTU). Tests have shown that turbid water reduces the effectiveness of solar disinfection, since the suspended particles scatter the radiation by deflecting it in all directions. An increase in water depth also reduces the amount of radiation able to pass through the entire water column.

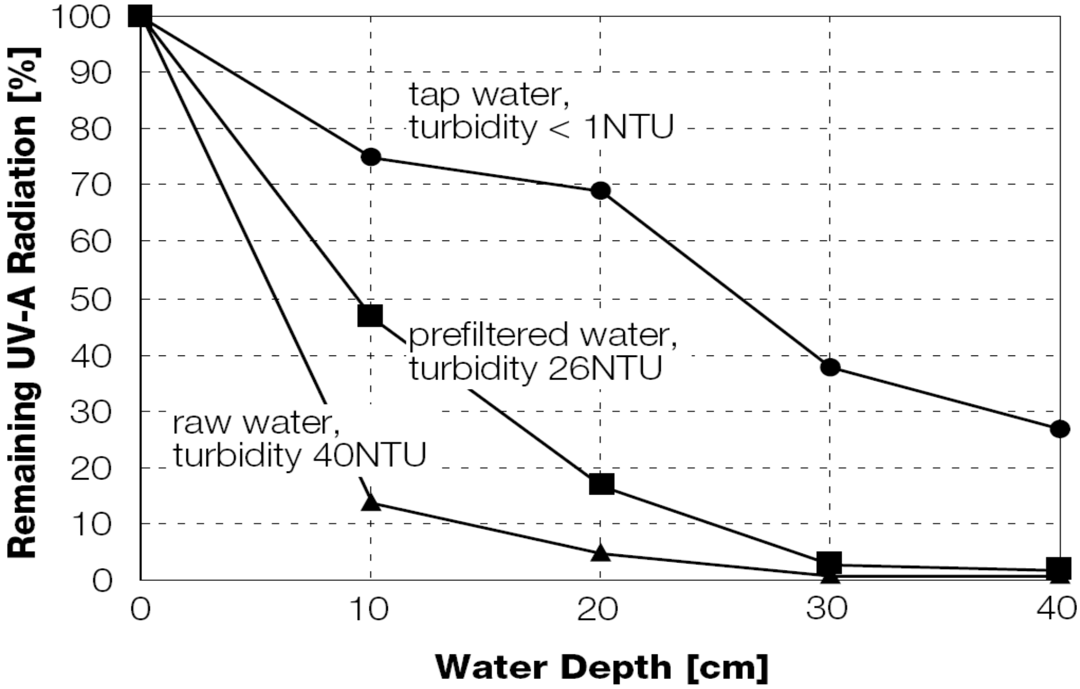

Figure2.5: Effect of turbidity & water depth on solar disinfection (EAWAG 2003)

Turbidity reduces the intensity of the solar radiation, protects microorganisms from being irradiated by concealing them, and hence, reduces the overall disinfection efficiency. It is, therefore, highly recommended that the turbidity of the water measure no more than

30NTU. If turbidity is >30NTU, it is necessary for a pre-disinfection turbidity removal step to be implemented [18].

As stated the principle that SDWT process applies is either using the germicidal band or thermal process (heating by IR). For this application thus it necessitates to use transparent material. And because the penetration limit of UV radiation is up to 10cm depth, small volumes of materials like plastic bottles are the prior choices.

The two main types of vessel recommended for SDWT are plastic polyethylene terephthalate (PET) bottles and thick, clear, plastic polyethylene bags(don't sufficiently present in the study area), since both are good transmitters of UV-A light. Polyvinylchloride (PVC) bottles are also effective light transmitters but are not recommended since they contain a high number of artificial additives which may harm human health. Some types of glass bottle can also be used (but are breakable).The type of glass to be chosen largely depends on the concentration of iron oxide in the glass [18]. PET bottles are chosen because they are found to cause no health effect and are durable [39].

2.3.4.4. Geographical, Seasonal and Daily Variation

The efficiency of the SDWT process is dependent on the amount of sunlight available. Solar radiation however is unevenly distributed and varies in intensity from one geographical location to another depending on latitude, season and the time of the day.

The seasonal variation depends on the latitude and is mainly responsible for the climate in that region. Regions near the equator encounter lower variance of light intensity during the year than regions in the northern or southern hemisphere. The seasonal differences of solar radiation are important for the applicability of solar water disinfection. Prior to the implementation of SDWT in a specific place, the seasonal radiation intensities need to be assessed. A total solar radiation intensity of at least 500 W/m^2 is required for approximately 6 hours for SDWT to be effective [18,29]. The solar radiation intensity is also subject to daily variations. With increasing cloudiness, less radiation energy is available. During completely overcast days the UV-A intensity is reduced to one third of the intensity recorded during a cloudless day. During very cloudy days therefore, the SDWT bottles have to be exposed for two consecutive days to reach the required radiation dose and to ensure the complete inactivation of the pathogens. The most intensive (irradiative) times in a day is found to be from 9am-3pm in each day.

Studies in different countries have identified the most promising regions. The most favorable regions for SDWT are located between latitude 15°N and 35°N (as well as 15°S and 35°S). These semi-arid regions are characterized by the highest amount of solar radiation. Over 90% of the sunlight touches the earth as direct radiation due to the limited cloud cover and rainfall (less than 250mm rain and usually more than 3000 hours of sunshine annually).

The second most favorable region lies between the equator and latitude 15°N and 15°S. Due to high humidity and frequent cloud cover, the amount of scattered radiation in this region is high (about 2500 hours of sunshine annually) [18, 29].

It is important to note that the majority of developing countries are located between latitudes 35°N and 35°S. Therefore, they can rely on solar radiation as an energy source for solar disinfection of drinking water.

Ethiopia lies within the tropics (3^0N to 18^0N latitude), a zone of maximum insolation (within 35^0N & 35^0s) as suggested by researchers. This is the region which is highly comfortable for the intended purpose.

Generally, northern Africa including Ethiopia is the area where there is the maximum intensity and duration of sunshine over the globe, and as much as 4,000 bright sunshine hours are received in a year.

2.3.5.Enhancing the SDWT Efficiency

Different studies have been conducted on how to enhance the SODIS efficiency. The attempts are on use of solar collectors, painting the bottles, use of reflective surfaces, agitation and the like.

Some tests with a simple solar collector to investigate the energy transfer from reflective and absorptive surfaces have been conducted by Loring Green as presented by SANDEC report No6/02. The first test he conducted was to demonstrate the temperature increase when a foil lined box was used to increase energy collection. The first test started at 9am at a water temperature of 21.1°C. At 2pm the temperature was 42.5°C in the half-blackened PET bottle kept outside the collector, while it was 66.5°C in the half blackened PET bottle kept in the foil lined box.

His second round of tests was conducted to compare the energy transfer from shiny and black surfaces around the bottles. For this test he used two identical plastic tubs lined with Aluminum foil to increase the area of energy collection.

In one tub the foil was shiny and in the other tub, the foil was painted black. The weather from 9 am-2pm was: air temperature increasing from 23°C to 28.3°C, light and variable winds and a very thin layer of cirrus clouds at 9 am getting somewhat thicker until 2pm.

Thickening clouds and a lowering sun angle after 2pm caused the temperatures to decline thereafter. The test started at 9am with a water temperature of 24.1°C. By 12am, the temperatures were 47.4°C in the black tub and 56.5°C in the shiny tub. By 2pm the water temperature in the black tub had risen to 54.7°C and the water in the shiny tub to 65.0°C. Tests conducted in Dublin, Ireland by [40] further evidenced the work.

Table 2.1: Temperature increase in shiny and black colored collectors

Hour	Black colored reflector	Shiny reflector	Air temperature
9.00	24.1	24.1	23
12.00	47.4	56.5	28.3
14.00	54.7	65.1	

They showed using a water container with a foil backing, result in increased rate, which is due to the higher effective UV-A radiation passing through the water (back and forth), and also due to the slightly higher temperatures achieved in the disinfection vessel.

Painting the half of the container black, whose face is not exposed to the sun, will result in a higher temperature, which will in turn, lead to greater thermal inactivation of the microorganisms, [18]. However, if the solar radiation is not sufficient to raise the water temperature to between 50^0C and 60^0C, at the site where solar disinfection is being undertaken, painting the lower face of the water container black may be of no use [23].

Therefore these findings can lead one to the conclusion that similar or higher results could be obtained in the study area as the ambient air temperature as well as the water temperature is quite higher than the ones stated. The ambient air temperature of the area is greater than 30^0C and even reaches 40 and above during the dry seasons. The water temperature is 25-28^0c for most water schemes. And as it is observed that the water temperature rises above 50^0c, half painting could be an important consideration.

2.3.6. Effective Pretreatment Methods

As stated previously, for solar disinfection to be effective, the turbidity of the water is quite important. Different scholars have made an attempt to determine the turbidity range over which effective solar disinfection could be achieved. The researches conducted in Kenya have concluded that as far as there is sufficient solar intensity, solar disinfection is effective up to 200NTU [21]. But many researches conducted for SODIS application in Africa by many developed countries including SANDEC has finalized their findings stating SODIS effectiveness is quite high in the turbidity ranges of <30NTU[6, 7]. And taking consideration of the fact that many drinking water sources in developing countries are of high turbidity (>>30NTU),which often reduces the amount of intensity reaching the water body ,they have suggested different pretreatment technologies.

There are various methods of reducing the amount of particulate matter in highly turbid water, the simplest of which include sedimentation, coagulation, flocculation, and filtration.

2.3.6.1. Sedimentation

Sedimentation is a process of solid-liquid separation that allows suspended particulates to settle to the bottom of the water vessel or tank. A common method of sedimentation is to simply store and allow the water to settle. After several hours or more, the supernatant can then be poured off from the top of the container. Settling for one day can lead to a substantial reduction in turbidity and >50% reduction in bacteria due to natural die-off since conditions within the container are generally not conducive to their survival [41]. In waters where the suspended particulate is very fine (clay particles), sedimentation may not occur even after allowing the water to stand for several days [41]. Simple plain sedimentation is a long history for the societies where this study is conducted. This is because they have been accustomed to live with surface water sources without any option for centuries. As a result they store their water in containers made of clay which is often with sizes of up to 200L and live it for a while until some improvement in turbidity is observed.

2.3.6.2. Filtration

For hundreds of years, various types of filters have been used to separate particulate matter from water. The basis of filtration is to physically strain, or capture, particles that are larger than the effective pore size of the filter.

Bio Sand

The Bio Sand filter (BSF) is an intermittent, household-scale slow sand filter. These filters are mainly used in individual households, with the most common type of BSF being a concrete or plastic container approximately 1m high with 0.3m sides. Water is then poured and allowed to trickle through the sand-filled container with the resulting filtered water available via an outlet pipe. The top layer of sand is particularly crucial in that a bioactive layer grows here. This layer helps to reduce disease-causing organisms. A perforated plate is usually placed on top of the sand to prevent disruption of the bioactive layer when water is poured through. The BSF has a flow rate of up to 60L/hr, depending on the size of the unit.

Tests have shown that the filter removes a large amount of the turbidity, as well as between 80% and 100% of the bacteria and protozoa if it is properly used and maintained. Less than 90% of the indicator viruses are also removed. This is in good agreement with the study by [42] @ Addis Ababa university science faculty, microbiology department. The disadvantages of this system are that it is relatively expensive, bulky and requires a certain level of technical knowledge and maintenance, in order for the system to run efficiently.

2.3.6.3. Coagulation

Coagulation is the electrochemical process of aggregating the suspended and colloidal particles in water. These aggregates are called “flocs”, which are heavier and settle out at a faster rate due to the increased gravitational effect. In order to optimize coagulation, there are 3 mixing regimes which should be adhered to. These are:

Rapid Mix – Once the coagulant has been added, the water is mixed rapidly in order to distribute the coagulant evenly amongst the suspended particles.

Gentle Mix – After rapid mixing the water, a more gentle mix regime should be adopted. This promotes particles to aggregate (without breaking up) in a process called flocculation. If the duration of gentle mixing is insufficient, then poor agglomeration of particles will result.

Settling – After flocculation, the water is left to stand, giving time for the flocs to settle [43].

Once the particles have settled, the supernatant water can be decanted or filtered. The following table shows the factors which generally affect coagulation:

Table 2.2: Factors Affecting Coagulation [44]

Coagulant characteristics	**Physical characteristics**	**Raw water characteristics**
Coagulant type	Settling time	suspended solids
Coagulant dose	mixing intensity	Temperature
Proper solution makeup & dilution	coagulant addition point	Alkalinity
Proper Coagulant age	proper coagulant feed	Presence of Microorganisms & Colloidal Species

A) Aluminum Sulphate (Alum)

Aluminum sulphate, or alum as it is usually called, is the most commonly used coagulant world-wide. It is found as a white to off-white lump or powder. Iron salts such as ferric chloride and ferrous sulphate are widely used coagulants.

In Ethiopia there is a share company producing alum at Awash Melkassa. Though it is produced in the country, it has got some limitations for use especially at house hold level. It's application is highly affected by the above mentioned factors, especially by the raw water character tics and as it requires skill man powers for dosing, it's no more applicable at house hold level. It's availability at the households location, its cost as well as its effect on health makes it the least choice at house hold level.

B) Moringa seeds

Generally, coagulants are used for (physical and chemical) purification of turbid raw waters [44]. At very high turbidity the water can no longer be adequately treated by using filters. Coagulants have to be applied to transform water constituents into forms that can be separated out physically. In large scale treatment plants Aluminum Sulphate is used as a conventional chemical coagulant. As an alternative to conventional coagulants, Moringa seeds can be used as a natural coagulant (primary coagulant) in household water treatment as well as in the community water treatment systems [45, 46, 47, and 48]. Natural coagulant properties were found in 6 different Moringa species by laboratory studies [45]. It is found that the seed collected from a single tree can treat up to 30,000litre of water.

The seed kernels of Moringa contain significant quantities of low molecular-weight, (water-soluble proteins) which in water form a dimeric cationic polyelectrolyte [49]. When the crushed seeds are added to raw water, the proteins produce positive charges acting like magnets and attracting the predominantly negatively charged particles (such as clay, silk, bacteria's, and other toxic particles in water). The flocculation process occurs when the proteins bind the negative charges forming flocs through the aggregation of particles which are present in water [50]. These flocs are easy to remove by settling or filtration. The material can clarify not only highly turbid muddy water but also water of medium and low turbidity. The level of turbidity influences the required time for the flocculation. As with all coagulants, the effectiveness of the seeds may vary from one raw water to another. The practical application of dosing solutions is exactly the same as for all other coagulants. Studies have been carried out to determine the potential risks associated with the use of Moringa seeds in water treatment. To date, no evidence has found that the seeds cause secondary effects in humans, especially at the low doses required for water treatment.

Families of Moringa, named Moringacea are multipurpose trees. Their leaves are good sources of nutritious food and are of good medicinal value too.

Moringa oleifera seeds contain 35% to 40% oil by weight [52]. It can first be processed to yield a high-quality edible vegetable oil “high in oleic acid” [46]. The oil of course resists rancidity [52]. Commonly referred to as Ben oil, its potential value within the household for cooking, smoke-free lamp fuel and the manufacturing of soap should be examined. In addition, a little coating of oil atop exposed water containers will help destroy mosquito larvae, and thus reduce the threat of malaria and other deadly insect-borne diseases. Of particular importance, the seed cake (presscake) remaining after oil extraction still retains the active flocculating properties for removing turbidity, without diminished efficacy [52].

Since the oil possesses local market value, adoption of the presscake as a coagulant is overwhelmingly advantageous when compared to the use of seed powder. Therefore, if possible it is recommended that the household oil-extraction be implemented beforehand to capture value-added commodities.

Generally speaking no part of the plant is useless. Studies show that it is a long history that these species are diversified in southern part of Ethiopia.

It is grown and cultivated in many tropical and sub-tropical regions in the world including in Ethiopia. One major advantage of the Moringa seeds is that they, unlike alum, are effective regardless of the pH of the water. Furthermore, it does not change the natural alkalinity of the water [49].

Studies have shown that Moringa seeds show turbidity reduction efficiencies of greater than 80%, with this percentage higher in waters with a higher initial turbidity [53].

Table 2.3: Optimum dosage of Moringa Oleifera for waters of differing turbidity [50]

Sample	Moringa oleifera conc. in mg/l	Turbidity (NTU)		Turbidity removal %
		Initial	Final	
Medium Turbidity	160	87.8±2	21.3±1.7	79±2
High Turbidity	300	194±3.8	22+2.2	89±3.1
Very high Turbidity	400	390±4.5	23.6±3.6	94±4.1

In Summary the main aim of selecting one of the aforementioned particle removal methods is to lower the turbidity to <30NTU, which is the allowable range for solar disinfection. All of the processes also remove a large percentage of the bacteria and protozoa populations, which attach to particles in water. All these approaches add an additional treatment step and, therefore, increase the complexity, labour and, in most cases, the financial cost of treating the water. It would therefore be most appropriate to select a system which removes the most turbidity at the lowest cost, and, to select a system that is available in the target location. It is studied well in the Ethiopian rift valley [48]. The tree is found in the target area too. The Miracle tree is an all over purpose tree, it is proved that it can treat water source that is hard& fluoride reach. It is also proved that the plant have the potential to reduce the microbial load up to 90% [59]. Its effectiveness plus the lower finance it requires thus makes it the preferable one among the aforementioned alternatives. Interestingly Moringa is in use by the local people of Guba as food. And I have been informed that they sell the leaves of the tree to the Sudanese people at high cost per kilogram. The regional food strategic plan has also given much emphasis to the plant and is on large diversification activity. The project on Sherkole Woreda on seed germination is one that further strengthens the attempt of using the seed as pretreatment aid in similar Woreda where the technology is deemed to be applied.

Therefore to compensate for the turbidity variability with season and optimize the process of treating water at the household's level with solar energy, it necessitates to optimize the Moringa dosage rates in the context of the society under study with development of simple pretreatment unit with the materials found at the societal level and operable with the skill of the society.

3. Materials and Methods

3.1. Research Design and Methods

3.1.1. Source of Data

Primary data were obtained from analysis of water sources that are in consumption by the society in Guba Woreda. The challenge while attempting to generate the data was the variability in turbidity characteristics of the water sources. The other challenge is the unknown bacteriological contamination level of the water sources. This necessitates characterization of the water bodies. As well to conduct microbiological lab on samples collected from most water types namely river, developed schemes, ponds and streams. But the results show relatively lower number of yellow colonies (<50CFU/100ml). And thinking that this lower value couldn’t clearly show the effect of the factors, it was managed to look for other indicative sources like water schemes in proximity with pit latrines and after 24 hrs incubation it gives 100CFU/100ml.

The lauryl sulphate broth media preparation was made at the Assosa water, mine and energy resource development water laboratory. And finally bacteriological labs were conducted onsite to evaluate the factor combinations. The potential of Moringa on turbidity reduction was evaluated through seed extract preparation using locally available materials.

3.2. Study Variables

E-coli (fecal coliform) are selected as study variable for this study. Three factors are taken into consideration to investigate their effect on the response variable, namely volume of container, turbidity and duration.

3.3. Samples Collection, Transportation and Storage

Water samples were collected from each representative area in sterilized (in Assosa water laboratory) plastic bottles. Some chemical parameters like pH and physical parameters like turbidity are analyzed at the sample point. But samples for bacteriological analysis are kept in ice box and transported to the woreda water bureau for analysis.

3.4. Experimental Procedures

As can be seen in ANNEX 3 all study parameters were determined based on American standard methods for examination of water and wastewater [54]. The available standard procedures and apparatus listed in the annex were used.

3.5. Experimental Design

The experimental design implemented is full factorial (3factors Time, volume, turbidity) with 3 levels 3 replication of each level: the response variable, microbial mass inactivation was recorded over the time intervals set. Membrane filtration method of microbial analysis was employed using lauryl sulphate broth as culturing media.

Independent factors (f): Three; container size, water turbidity, and time of exposure.

Factor levels (L): 3, for all factors.

Number of runs: $L^f = 3^3 = 27$

Replicate: 3 runs= 3×27 = 81

Response: Faecal coliforms (Microbiological water quality indicators)

The three independent factors and their levels

Container size (in Litre): 1, 1.5, 2

Turbidity (NTU): <30, 30-60, 60-90

Duration: 1.5hr, 3hr, 4.5hr

3.6. Statistical Analysis

The data is analyzed at 95% confidence interval. The developed model values have been found to match the actual values resulting in a p-value of <0.0001. The root mean square value is 0.99. This suggests that the data generated is very reliable and best fits with the predicted value. It also shows that the variability in the response value is 99% accounted by the factors under consideration. Model prediction profile has been run to determine the optimum factorial combination giving the optimum response of 0 microbial load at 2L, <30NTU turbidity and 4:45 hour total duration of exposure. Statistically no significant difference is observed between the two set of data generated in the two months January and February. The prediction profiler gives almost same optimum condition in both cases with same p-value &R-square values.

3.7. Method of Fecal Coli Form and Physico-Chemical Determination

HACH model JMP kit incubator was used to determine the colonies of fecal coli form in the water samples following bacteriological analysis standard methods. The HACH models turbidity meter, P^H meter and thermometers were used to determine water Turbidity, P^H and Temperature.

3.7.1. Membrane Filtration Method

This is one of the methods used in bacteriological analysis. In the method the sample to be analyzed is filtered using filtration apparatus. The membrane filter technique, which involves direct plating for detection and estimation of coliform densities, is effective for detecting bacteria of the coliform group and it is the best techniques currently available [54]. The set up of the method is shown in Fig 3.1. List of accessories, chemicals and procedures used in the method are attached in ANNEX 4.

Fig 3.1 set up membrane filtration method

3.8. Sample Analysis and Interpretation

3.8.1. Water Sample Analysis

All samples were analyzed for turbidity and faecal coliforms on- site using field kits. To determine the presence of faecal coliform in the water samples, standard membrane filtration methods were used as described in membrane filtration techniques [54]. Turbidity also measured using Turbidimeter (HACH- 2100P model Turbidimeter).

This technique involved filtering water through a membrane that retained fecal coliforms, incubating this membrane on a growth promoting medium (lauryl sulphate broth) and then counting the resultant FC units.

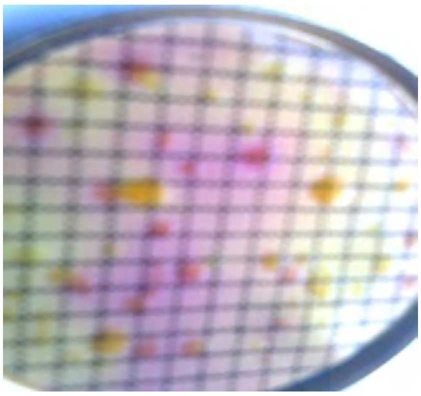

Figure 3.2: Well Matured Yellow Colored Fecal Coliforms in Raw Water

An ideal sample volume of water 10ml were taken at each time level set. Samples were filtered. Using sterile forceps and a sterile membrane filter paper (0.45μm pore sizes, 47mm in diameter, sterile and gridded from WAGTECH) was placed on the membrane filter support assembly (from WAGTECH). Funnel unit were placed carefully over the filter support assembly and were locked in place. The sample were mixed thoroughly by shaking for about 30 minutes and poured in to the funnel assembly, then the entire volume of sample were filtered through the membrane-filter by applying vacuum pump. Funnel and membrane-filter assembly were rinsed by sterile dilution water.

Up on completion of the filtration process, vacuum were disengaged, unlocked and using a sterile forceps funnel were removed and membrane were removed immediately and placed on the culture media with a rolling motion to avoid entrapment of air in metal Petri dishes. Finally the prepared culture dish incubated for 22 to 24h at 44 ±0.5 ^{0}C. Up on completion of incubation period, typical coliform colonies (yellow) were seen on the surface of membrane filter paper. Colony counts on the filter paper were determined using a magnifying glass. The lab setup is presented in fig 3.1.

4. Result and Discussion

The following chapter provides result of laboratory analysis made for raw water characterization; study of effects of parameters such as container size, turbidity and time (duration) on treatment (E-coli removal capacity) efficiency of the prevailing solar energy in the study area. New ideas developed to overcome the limitations of the technology are presented.

Figure 4.1: Field investigation of the technology under real sunlight condition and recording of timely temperature readings

4.1.Results

Water samples were taken from different sources that are thought representative from all types being in use by the society. Prior to identification of the samples to be used for the assessment of the efficiency of the technology, raw samples of size ranging from 5-20ml were set for analysis. The result of analysis is presented in the following table.

Table 4.1: Microbial Analysis Result of the Available Water Sources in the Area

Sample source	Sample size	Fecal Coli form (CFU/100ml)
Abbay river	10	30
Beles river	10	25
Aymo river	10	20
Supply system (guba town), Reservior.	20	2
Consumers faucet	20	3
House hold storage	20	5
Shallow well	20	2
Hand dug well, developed	20	10
Hand dug well, undeveloped (nearby pit latrine)	5	96
Pond	5	95

The final technological assessment, thus bases itself on those samples with relatively higher microbial load. Thus samples were taken into PET containers of size 1, 1.5,2 liters, with turbidities ranging from 30-90NTU. The duration of exposure is set from 9am-1:30pm. The samples were analyzed in triplicates.

The analysis was conducted twice in two months, January and February, simply to see if there is significant difference in results within a season. And no significant difference is observed between the analysis results of both months. The result obtained during the first month (January) is presented in the following combinational table.

Table 4.2: Average Combinational Table, Test Result for the Month January

Container size	Turbidity	Duration	Microbial mass
-1	-1	-1	67
-1	-1	0	40
-1	-1	1	0
-1	0	-1	69
-1	0	0	42
-1	0	1	0
-1	1	-1	70
-1	1	0	45
-1	1	1	0.7
0	-1	-1	71
0	-1	0	48
0	-1	1	0
0	0	-1	72
0	0	0	37
0	0	1	0
0	1	-1	69
0	1	0	48
0	1	1	0.3
1	-1	-1	72
1	-1	0	49
1	-1	1	0
1	0	-1	71
1	0	0	53
1	0	1	0
1	1	-1	73
1	1	0	57
1	1	1	2

The statistical analysis results i.e. summary of fit and the analysis of variance results are presented in tables 4.3, 4.4 but the whole model, the parameter estimate, and effect test results are shown in ANNEX 6. The analysis results in R-square and R-square adjusted values of 0.99, which is a good indicator of best match between the actual data and the prediction model data. The AVOVA result also supports this idea giving rise to p-values of <.0001.

Table 4.3: Summary of Fit

RSquare	0.992571
RSquare Adj	0.990342
Root Mean Square Error	3.139229
Mean of Response	39.81481
Observations (or Sum Wgts)	27

Table 4.4: Analysis of Variance (ANOVA) Results.

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	26332.559	4388.76	445.3442
Error	20	197.095	9.85	Prob > F
C. Total	26	26529.654		<.0001

4.2. Discussion on the Main and Combinative Effects

4.1.1. Effect of Container Size

The statistical analysis result displayed through parameter estimate and effect test demonstrates that container size highly affects the process which is in good agreement with the study by [55]. As well the irregularity in shape of the containers within the specified depth (≤10cm) has been found to cause no effect on the efficiency of the technology. The tRatio values suggest that it is the second factor next to time affecting the process under situations considered. However, P-values of about 0.0001 clearly indicates that it affect the process highly.

Table 4:5 Effect of container size on the response

Container size(L)	Turbidity(NTU)	Duration(hrs)	Response(FCU)
1	30	4:30	1.5
1.5	30	4:30	3
2	30	4:30	4.5

4.1.2. Effect of Time

Duration is one of the factors that affect the process**.** Studies indicate that the intensity of the sun is very weak early in the morning up to 9am [56]. And this is thus set as the start time of the analysis. The result obtained within the first two hrs of exposure gives no significant change in the concentration of the microbial mass. This indicates that the intensity of the sun even in the next two hours is weak. And the result obtained within the next two and half an hour reveals that the intensity is quite high to bring up the UV and thermal effect. The solar intensity during the month of study is on average >700W/m^2. This indicates that duration of exposure is one determinant factor. This is what is reflected by the analysis results using JMPIN 5.0.1 software package in the parameter estimate, effect test and duration leverage plot found in ANNEX 6. The maximum sum of square in effect tests and the larger negative number (slope in the leverage plot) in the parameter estimate clearly indicates that time is the main factor among the factors under consideration.

Table 4.6: Effect of time on the response

Duration(hrs)	Turbidity(NTU)	Container size(L)	Response(FCU)
1.5	30	1.5	70
3.00	30	1.5	36
4:30	30	1.5	1.5

4.1.3. Effect of Turbidity

Turbidity measures the optical properties of liquids. Suspended particles can absorb and scatter light as it passes through. Consequently, highly turbid solutions can severely limit the amount of light penetration, thus reducing the efficiency of the SODIS process. For effective solar disinfection, waters should be less than 30 NTU to ensure safe drinking water [57].

This and the other findings enforce one to characterize the available drinking water sources in an area before recommending the technology. The result of characterization during the dry season thus, ends with low to medium type of turbidity as presented in table 4.5.

The statistical analysis result as shown in tables 4.3& 4.4, the effect test and the turbidity leverage plot shown in ANNEX 6, indicates that turbidity of the range taken has a very weak effect on the process relative to the other two factors taken. This is contrary to the findings of [18, 57].

But is in good agreement with the study stating that SODIS is effective up to water turbidities of 200NTU provided that there is sufficient solar intensity to rise water temperature above 55^0c [19]. And this condition seems to exist in the area of the study as water temperature rises above 50^0c within 4-4:30hrs time’s interval in all the samples. And the fact that the turbidity in this study is lower than the one considered might bring the effect at relatively lower temperature (50-54^0c) [19].

However from water quality point of view, turbidity is one of those physical water quality parameter for which standard has been set. This is because it detracts aesthetic value of the water. That is it highly affects the water consumption trend of community.

And has the power to affect the socio-economic activities of the society. Peoples may divert to consumption of drinks (like beverages) as the case is true for the area of study.

This and other related issues will enforce one to look for local, affordable and manageable pre treatment option prior to SODIS application in an area.

But it should be noted that under situations in which it is impossible to perform the pretreatment process, SODIS application during the dry seasons is more than consuming without treatment.

Table 4.7: Effect of turbidity on the response variable

Turbidity(NTU)	Container size(L)	Duration(hrs)	Response(FCU)
30	1.5	4:30	3
60	1.5	4:30	4
90	1.5	4:30	5

4.1.4. Combinative Effect

The statistical analysis result of the effect tests and the leverage plots in ANNEX 6 shows that the interactive effect of two of the factors at a time is not significant except the container size-duration interaction with p-value of <0.05.

4.1.5. Thermal Effect

One of the mechanisms behind the technology is temperature effect. Temperature above either 45^0c, or above 50^oc, results in synergestic effect [19, 21, and 55]. In this study tempratures of 45^0c and greater than 50^oc are achieved for most of the samples after three hrs duration of exposure. And has remained improving for the rest of exposure times. In association with this a dramatic reduction in microbial mass was observed. Indicating that the effect of temprature increase above 45^oc has a significant effect on the rate of disinfection. And thus it could be said that it is this temprature rise that masks the effect of turbidity within the specified range [21].

However this rise in temprature have some sort of limitation while consuming after treatment. Immediate consumption of such water sources is impossible. It takes longer time even to be in balance with the ambient air condition.

Neverthless technologies are within the hands of our community though is not well explored. We know that the modern distillation processes had been and is being in practice by our illitrate mothers. Similar activities are observed in rural mothers of the berta society in assosa. They produce matterial called,Albrick with comparable efficiency with the modern refrigrators with relatively long storage times (1-2hrs). It is made of clay. It is narrow mouthed which makes it ideal for safe storage of treated water like the one by SODIS. Its size ranges from 5-10 litre.

Figure **4.2: Albrick, an Alternative Local Water Cooler and safe Storage on Sale in Shops**

4.1.6. Optimal settings

One of the limitation of SODIS Technology is the penetration range of UV. And some studies State that % of UV reaching the water surface is very limited to depths of <10cm [55].

This has imposed a limitation to the container sizes to be employed for the process. And thus the prime objective in this sort of analysis is to set conditions that could give the most reliable result at optimal settings of the factors. The analysis result using JMPIN 5.0.1 software package gives rise to an alternative set of optimal setting. It is better chosen that the setting at maximum size of 2 liter with disinfection time of 4:45hour-and turbidity ranges of <30NTU.

4.2. SODIS Application Limitations and New Ideas to Overcome It

The process of water treatment using solar disinfection is surrounded by limitations [17, 55]. One of the limitation is the turbidity level over which it should be applied both from point of efficiency and aesthetic value of the water for consumption. Thus looking for local solution to overcome such limitations is worth full if the technology is to add some value to the rural communities who are under the victim of safe water deficacy. And natural solutions to drinking water treatment based on plant sources are of no comparable effect [46]. Thus the natural coagulants which have not been in use for such purpose in Ethiopia though their potential has been investigated before decades, has been selected as the prime candidate and started its miracle effect on turbid waters around Guba Woreda [48]. But characteristics of the water sources in the area are important for its appropriate application.

4.3. Water Source Characteristics of the Study Area

Water characterization:

The big challenge while undertaking such a study is obviously determining the characteristics of drinking water sources in the area. This is because turbidity has been observed to affect the technology while applying. And because no full data's are available for the area, water turbidity characterization was conducted. Samples were taken from the main drinking water sources that the society have been accustomed to drink. Unfortunately most water sources are found to be within the turbidity ranges recommended by most researchers (i.e. <30NTU). But it should be noted that this result holds good for the seasons when this analysis is conducted, especially for developed schemes, surface water and sand scratched sources. The other sources like ponds, undeveloped wells still require pretreatment.

Some experiences from the society side shows, there is a trend of shifting from water source to the other depending on seasons. That is during the dry season they use surface water sources as it is in sufficient quantity than developed ones. And during the summer times they use those developed ones as well as the nearby streams as their volume increases. And the fate of those without such an opportunity is, using the surface sources followed by plain sedimentation.

In summary the turbidity of most sources, is found to be within the standards (both national &WHO). And the turbidity of the extreme cases is 30-100 NTU. But taking into consideration of the fact that some exceptional cases might exist out of my reach & some external forces like non-seasonal rain & disturbance by animals can create higher turbidities, considerations have been taken to account for this sort of variability.

Table4.8: Water Characteristics of the Area from January-February

Water source	Turbidity (NTU)	Water temperature	Water pH
Developed schemes (wells& supply system)	<5	22-25	6.8-7.2
Surface water (Abbay, Beles, Aymo rivers)	10-30	23-28	7.5-7.8
Sand scratched water	20-30	23-25	7.4
Undeveloped wells dug by households	10-50	22-23	7.6-8.3
Ponds, streams in common use with animals	<100	23-28	8.2-8.4

4.4. Turbid Surface Water Clarification Using Natural Coagulants

To treat surface water, the equivalent weight of press cake or seed powder required to make up a crude extract solution is dependent upon the turbidity. For that matter after making thorough literature review an attempt has been made to determine the Moringa dosage rates within the context of the society under study. And after grinding the sun dried Moringa seeds with the household's stone mill, a solution of the powder has been prepared taking 2.5g (equivalent to 9seeds) of the powder.

The powders were first dissolved in 100ml of distilled water (water from developed schemes with lower turbidity value <5 NTU can often be used or previously clarified water). The whitish paste formed is further diluted by adding 150 ml of water. This produces 10g/l of stock solution. The following water samples of turbidity 50, 100,150,200,250,275,300,350 and 400NTU were taken. Solutions of size ranging from 5-40ml were taken from the stock solution, corresponding to solution strengths of 50, 100, 200, 300, & 400mg/l. The result of the field study is shown in table 4.5.

Table 4.9: Moringa Dosage Rates and Its Treatment Efficiency

Initial water turbidity (in NTU)	Moringa dose (mg/l)	Final turbidity (NTU)	% Removal
50	50	15	70%
100	100	20	80%
150	100	25	83%
200	200	23	88.5%
250	200	25	90%
275	300	24	91%
300	300	23	92.3%
350	400	20	94%
400	400	21	95%

It should be noted that Table 4.7 provides an overall general (rough) guideline for dosage rates. In light of logistical complications within a primitive household level of action, i.e., the inherent variability of raw water conditions and dosage performance, it is recommended that simple village jar test procedures be undertaken to determine the best clarification dose.

The shelf life of the powder is investigated to be a month time if stored in dry plastic bags under dry and cool condition [60]. So considering the shelf life of the material a monthly preparation of the powder is recommended. The result obtained above is conducted over wide range of turbidity with the same Moringa concentration taking consideration of the variability in turbidity range within a season and even monthly. The result obtained can thus be represented on seed basis within the turbidity intervals taken. This is made considering the educational status of the community and availability of measuring devices while use. The turbidity ranges are classified as low, medium, high, very high and extreme.

Table 4.10: Moringa Dosage Rates (Seed Powder).

Raw water turbidity (NTU)	Dose range (seeds/liter)	Dose range (mg/liter)
<50 NTU (low)	1 seed/6 liters	50 mg/liter
50-150 NTU (medium)	1 seed/3 liters	100 mg/liter
150-250 NTU (high)	2 seed/3liter	200 mg/liter
250-300 NTU (very high)	1 seeds/liter	300 mg/liter
>300ntu (extreme)	4seeds/3litre	400mg/litre

Note that the average dry weight of the seed ending with clear paste solution is roughly 0.3g.

4.5. Sizing Simple Batch Mode Operating House Hold Level Pretreatment Unit

Once the appropriate dose of the coagulant is determined it is possible to size a simple pretreatment unit so that communities can produce their drinkable water in sufficient quantity for appropriate days. This avoids the redundancy of making the process on daily basis. Unless repetitive engagement in the process might cause some sort of being bord, which might finally end up with cease of the activity.

Considerations :

The following points are taken into consideration while making an attempt to size the unit.

- ♣ Availability and sufficiency of water collectors and storage units. But unfortunately it is observed that each household has been accustomed to produce and use pots of varying sizes ranging from 20-200L. Pots of cyclonic shape are chosen because of their improved coagulation- flocculation efficiency compared to the other shapes.

Figure 4.3: Local cyclonic pots

- ♣ Community size per house hold. Data from regional statistical agency suggests that the average regional house hold size is 7.

- ♣ Drinking water consumption per individual per day is assumed to be 2litre (assuming the average body weight is 60kg).

- ♣ Assumed storage day is 4-6 day. This is in consideration of the fact that communities particularly moves several hours to fetch their drinking water (usually using their donkeys), the burden actually resting on children's and women's posing significant impact on their schooling. The interview made for about 10 families in the study area support the assumption. They replied that because the water sources as well as farming sites are far away from their residence they once collect the water and thus uses it for a longer time i.e. 4-7 days. Imagine what aesthetic value this long stored water collected from unprotected source has? As a result of this it has been observed that the water consumption trend in such arid areas is quite low. And thus they are acquainted with drinking either beverages like locally produced Bordi, otherwise occasionally hot drinks like coffee in frequent basis moving from one house to the other, which costs most of their productive time. Can the cost of coffee permit them behave in the same way afterwards? Therefore considering the precious time of the local dwellers for farming, education and other activities 4-6 days of pretreated water storage can be taken from which an appropriate sufficient volume of water can be taken into the batch mode operating system shown in fig 4.7 or individual appropriate bottles for solar disinfection.

- ♣ Water turbidity of the range 50-300NTU.

- ♣ Availability of Moringa in the study area or within its neighboring woredas and zones. And it have been informed that it is available in the area & is in use as food source (its leaf) and some Ethio-sudanes people use its seed for water treatment and I guess they have acquired the knowledge from Sudanese people. It's also planted in large scale in area called Wobo Abbay found in Wombera Woreda. And the information obtained from the regional agricultural bureau shows that, currently large scale production has been planned in an area called sherkole at the former refugee camp in Assosa, and is in operation now.

Therefore, based on the above consideration the optimum size of the container (local pot) for the coagulation-flocculation purpose will be:

X=7person*2L/person/d*5d=70L≈3.5 jugs of 20L each………….................................4.1

But taking into consideration of the volume of sludge to be produced, and to account for some variability in consumption (like provision of water to guests coming to their village whether one wants or not, particularly by the Gumuz society), it necessitates to take safety factor value of 15%.

i.e. 70*0.15=10.5L…………………………………………………………………4.2

Thus, the actual size of the container will be,

70+10.5=80.5 L≈ 4 jugs of 20L each………………………………………………..4.3

The water turbidity of the area during the seasons except the rainy seasons is within 50-100NTU, the amount of Moringa required for this range of turbidity as shown above is 1seed/3L corresponding to 100mg/L.

Thus 80L turbid water requires,

80L*1seed/3L=27(8.1g)…………………………………………………………..4.4

Similarly for the extreme cases expected during summer, similar calculations could be made as follows. As stated in the paper the efficiency of the seed increases with increasing turbidity. And surprisingly same dose of the powder can be used over wide turbidity ranges of say 250-300NTU.

Thus for the same volume of turbid water with turbidity of 300NTU, the dose will be:

80L*1seeds/L=80seeds (24g)……………………………………………………….4.5

NB: it should be noted that faucets can be incorporated into the pots at some levels to avoid some sort of additional contamination.

Adjustment to the dosages can be made by conducting village level jar test. For this purpose there are health extension workers that can address it provided that they are trained well. And because water supply and sanitation professionals are allocated to each Woreda and Kebele, they can help extension workers in training how solutions could be prepared. The steps to be followed are attached in ANNEX 4.

4.6. Design of Batch Mode Scaled Up SODIS Unit

One of the factors considered to affect otherwise limit the SODIS application is the container size over which the technology can best apply (max of 2 liters). It is actually possible to design PET bottles of improved size with the thickness and depth (about 10cm), the technology requires. But the mold is usually imported from abroad and is thus what is not to be afforded and attempted with this limited time of work.

However ,as the main aim of this work is developing systems that can be manipulated by the society, an attempt is made on how to improve the limited capacity of the PET bottles that impart tedious type of work that may make the society to be board and may lead them cease the operation.

For that matter a simple batch mode, house hold SDWT unit has been developed using simple materials. Here itself everything is sought in the context of the local community's skill and economic status. Material selection was thus done in this context. Transparent hoses of (fiber braided reinforced) 1/2 inch (available sizes of lower diameter is preferable) were used. These types of hoses are water and high temperature resistant. Corresponding diameter holes were drilled to connect the PET bottles to the hose and the bottles in series. The hoses in the bottle were cut to make holes that allow water flow into the container. The bottles are oriented in a way that the head developed in the bottles is lower than the head at the entry point (entry bottle). This is merely to aid gravitational flow of the fluid into all bottles.

The arrangement of the bottles were in such a way that more bottles be utilized within small land area. The bottles were arranged in a way that the entry and exit points are the bottle mouths themselves as shown in fig 4.6.

BGR is one of the prime areas where bamboo trees are highly diversified. Bamboo stems are hollow structured materials which are thick and hard that they are believed to replace steel. So they can be used to simulate the purposes of hoses.

Sizes of the containers used can be determined based on the family size. For this study area actually the average family size is 7 and thus with the assumption that each individual can consume on average 2litres of drinking water daily, thus a total of 14 litre should be prepared daily. With the lower bottle size (1 liter) thus 14 PET bottles are connected through hoses. With the higher bottle size (2litre) thus same number of bottles can produce 28 liters of drinkable water. On an average 21 liters of drinking water can be produced with 1.5 liters bottle size.

In summary 14-28 liters of microbiologically safe drinking water can be produced daily using this batch mode operating system developed using locally available bottles of appropriate size. It should be noted that the number of container can be adjusted according to once family size. Use of corrugated iron sheet as the base holder can improve the thermal effect (leveled sand layers can be used in its absence).

Figure 4.4: Batch mode operating scaled up SDWT system

5. Conclusion and Recommendation

5.1. Conclusion

In this study it has been tried to investigate the potential of the green technology, SDWT. Different factors that affect the technology have been assessed. Three main factors highly affecting the process have been analysed for their effect on full factorial basis. Results were then analysed with JMPIN5.0.1 giving the optimum factorial combination of 2litre container (PET), water turbidity of <30 NTU and exposure duration 0f 4:35hrs resulting in optimum response values of 0FCU/100ml. Statistical significance ($p<0.001$ & RS=0.99) of the test results within the ranges considered reveal that, about 99% of the variability in the response value is imposed by the factors considered. And the result obtained can easily be adopted to other regions of the country where the water quality problems are claimed to affect the health of the community.

However, the water characteristics (mainly turbidity) & the prevailing weather condition in the area are quite important. But studies have confirmed that there is better or similar solar intensity data over wide areas of the following region, Afar, Somali and other peripheral areas [58].

The good news here is of course the lower turbidity ranges observed during the dry season over which the technology best applies. The availability of natural coagulants in the study area and existence in bulk in the southern parts of Ethiopia with higher treatment efficiency (70-95%), the artistic skill of the local society to produce pots of varying sizes sufficient for preparing water of desired quantity, further supports the idea of producing water of desired quality even during the worst cases (higher turbidity).

As shown in fig4.1 & 4.2 the sun shine hours and ambient air temperatures respectively are high enough that it is even possible to set the disinfection process twice a day particularly during the dry seasons (February -April). The water temperature rising above 45-50^{o}c is a good indicator that the thermal effect is within a range to cause synergistic effect. The availability of materials such as Albrick to cool the raised water temperature as well service as safe storage materials is the other added bonus.

The development of an appropriate size of pretreatment unit and the batch mode operating system, possibly with locally available material and the skill which is not beyond the scope of the community further strengthen the scope of the technology over wide seasons which might actually confront variability.

Therefore under strong sunshine conditions (February-April) >4:35 hours of exposure of water of relatively lower turbidity level (<30NTU) can get relieved societies which have been diarrheal victims with improved safe drinking water. Particularly children under 5 which are the prior victims of diarrheal cases will get relief.

And for the rest of seasons it is better to expose the water samples at least for 6 hours as the solar intensity for such times is relatively lower than the dry seasons but quite higher than $500w/m^2$ and water temperature of $>30^0c$ which are the threshold values[17].

The result from this study can easily be extended to the rest areas of the regions where the water sources are not safe (even for the water sources considered safe) but having similar climatic condition to this study area. These areas include Kurmuk, Sherkole and Menge as Metrological data’s suggested.

5.2. Recommendations

It is obvious that the prime question behind every activity is sustainability. And every technology we devise shouldn't' cause any treat both on human being and the environment. Different technologies are investigated for water treatment at house hold level. In this particular study one of the environmentally friendly and sustainable technologies which can be used at all societal level both literate and otherwise is dealt with taking one study area, guba. It requires materials not beyond what is available in rural areas. And though the study at field reveals it is applicable within some time interval, the following recommendations will make the technology self stand, potential and applicable in the study area within an appropriate time settings as stated based on seasons.

- ♣ The area of application should be within full sunshine range.
- ♣ Great care should be given to the sample orientation, should be oriented in a direction that the bottles face the incoming solar intensity.
- ♣ Improving the sample's absorption of IR with half painting is observed to improve the thermal effect .Therefore, half black painting followed by lying on shiny surfaces or rising the bottles on black surfaces is highly recommended.
- ♣ Having chemical treatments as an intervening option is also highly recommendable. For that matter ''wuha agar'' is the best alternative for exceptional times like rainy season and full cloud condition.
- ♣ It is observed during the field analysis that the initial water temperature affects the process efficiency and to compensate for this it is highly recommended that bottles should be raised early in the morning.
- ♣ Awareness creation has the highest credit to fully implement the technology. And as extension workers reach each household frequently, awareness can be created through them. The data from health offices reveal that there are about 32,000 health extension workers all over the country.
- ♣ The available solar intensity data indicates that there are areas where the result of analysis can be adopted to [59]. So the technology could be recommended to these areas like Afar, Somali and many peripheral areas of the country as shown in annex 7.

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Annexes

ANNEX 1: List of Apparatus

1.1 Materials & Instruments

The following materials and instruments were used for the research. The instruments are taken from BGWME resource development bureau bought for the bureau by UNICEF from WAGTECH international PLC. They all are potable. And thus can be used both in the lab and on field.

- **Bacteriological test kits with its accessories like**
  - ♣ Incubator
  - ♣ Incubator calibration kit
  - ♣ Membrane filtration apparatus
  - ♣ Forceps
  - ♣ Filter papers
  - ♣ Petri dishes
  - ♣ Paddle
- **Physical and chemical water quality analyzers**

The following instruments were used to measure the physical characteristics of the water samples taken.

- ♣ P^H meter
- ♣ Turbidity meter
- ♣ Thermometer

In this research the materials that are used are:

- ♣ Seed of Moringa

- ♣ Membrane filter, measuring cylinders
- ♣ Water samples
- ♣ Spice crusher or grinding mill and tea strainer.

ANNEX 2: List of Chemicals

Reagents and solutions used

The following reagents and solutions were used to analyse the samples.

- ♣ Lauryl sulphate broth (culturing media)
- ♣ Calibration solutions for turbidity (with turbidity ranges of 800, 200, 20, 0.02NTU).
- ♣ Distilled water

ANNEX 3: **Laboratory Procedures**

MICROBIOLOGICAL TEST PROCEDURES

- ♣ As is usual in all laboratory set up, all the materials used for the lab were First sterilized (in Assosa water quality lab).

Fig Sterilized Microbiological Analysis Accessories

Samples were taken from contaminated water schemes which are in use by the society and assessed.

Finally samples were analyzed for microbiological quality based on levels set. The American standard test procedure developed for membrane filtration method is followed (APHA 1998).

PROCEDURES FOR MORINGA SOLUTION PREPARATION

Seed solutions may be prepared from either seed kernels or the solid residue (Press cake) obtained following extraction of seed oil.

Seed kernels

- Matured seeds are removed from the pods, and shelled.

- Seed kernels are crushed and powdered (stone mill) and sieved (0.8 mm mesh or tea strainer in this case).
- The seed powder is mixed with a small amount of clean (100ml in this case) water to form a paste.
- The paste is then diluted to the required strength before using it (Dosing solutions can be prepared from 0.5 to 5% concentration, e.g. 0.5 to 5 g/l.).
- Insoluble material is filtered out using either a fine mesh screen or muslin cloth.
- The milky white suspension is added to the turbid water and stirred fast at least for a minute.
- Then the water must be slowly and regularly stirred (15 to 20 rotations per minute) in a manner the local societies stir their porridge for about 15 minutes.
- After stirring the treated water should be covered and left to settle for at least one hour. If moved or shaken before then, clarification will take much longer or fail to reach completion.

Procedure for conducting onsite jar test to account for seasonal variations

- Solution of the required strength (say 1000mg/L) is prepared following the same procedure as stated above using previously treated water or if possible distilled water, in say 500ml container.
- Three containers of equal size into which samples of equal size could be poured is required. Preferably containers of lower size may be up to 500ml or lower if available. This is to conserve the powder.
- Because the dosages could be among the three (100mg/l, 200mg/l, 400mg/L), recommended for the higher turbidity levels (>50ntu), these respective dosages will be added to the three water samples.

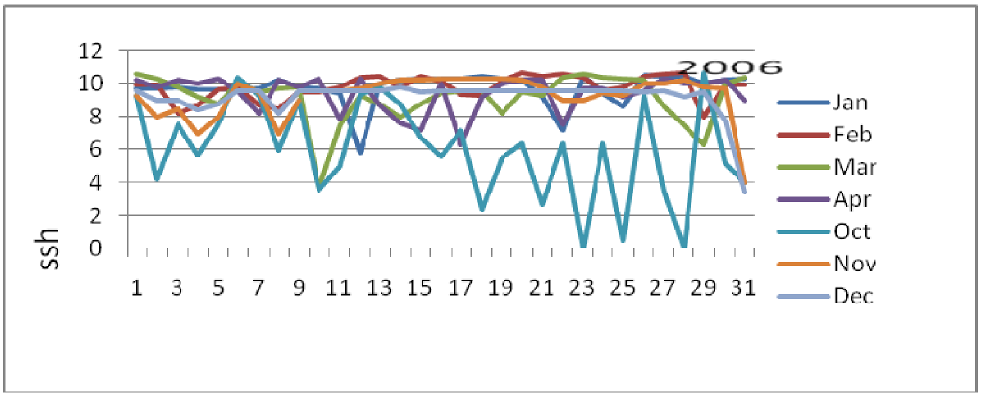
- ♣ Three persons are required to perform the flocculation-coagulation stages namely rapid mixing, gentle mixing and settlement as per the above procedure.
- ♣ Finally samples will be analysed by sensory evaluation and the one showing better result at lower Moringa dosage will be taken.

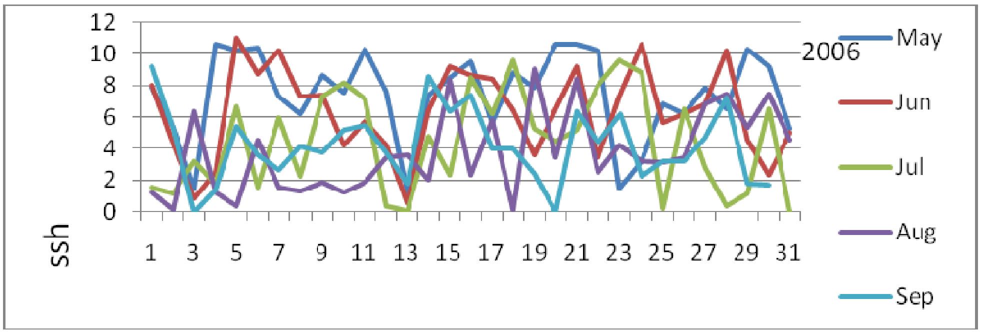
ANNEX 4: Metrological data

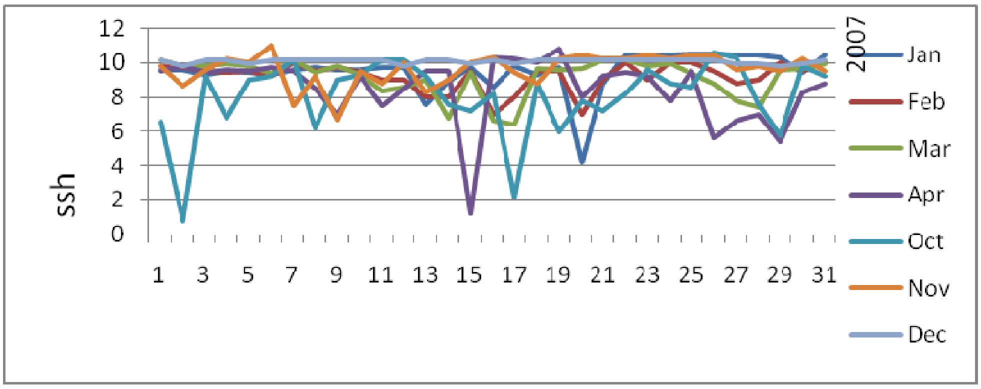
Available metrological data that can support the work were taken from national Ethiopian metrological agency. Mainly the sunshine hour and temperature data's as presented here.

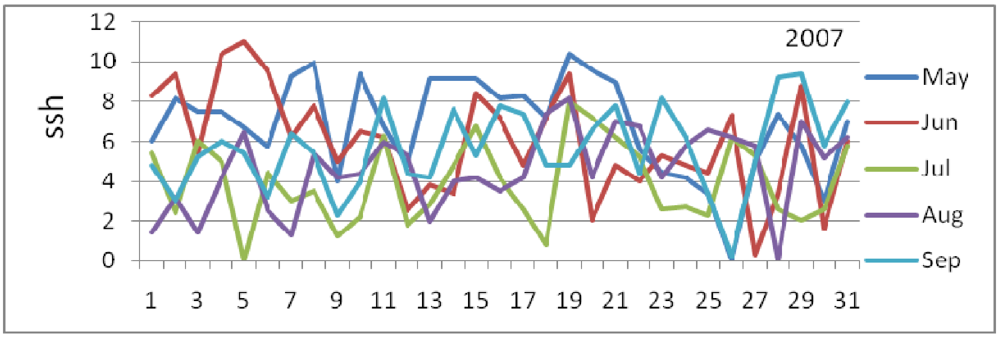
Sunshine hour data

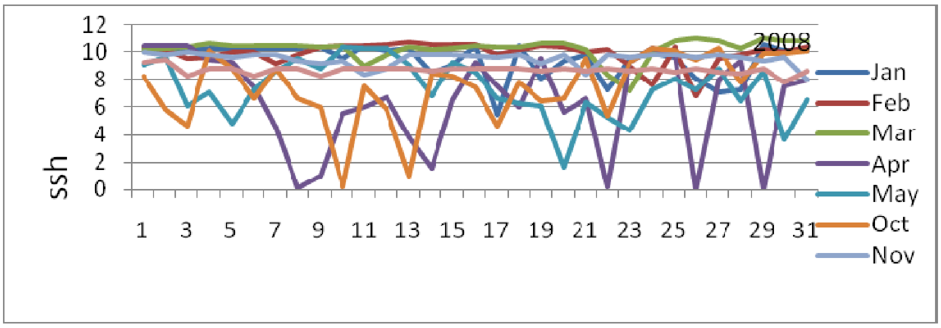
Some year data are shown here to show the daily variations within the dry season and the summer less sunny times.





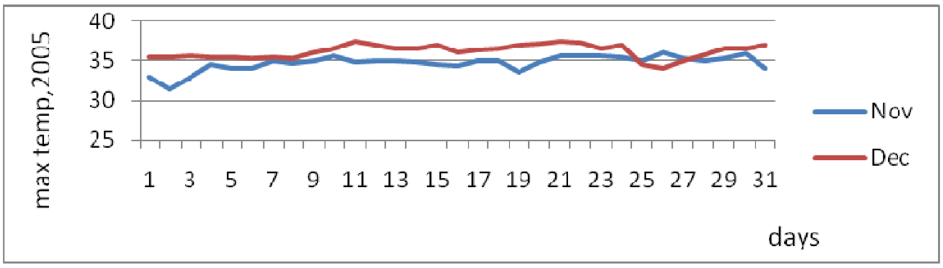


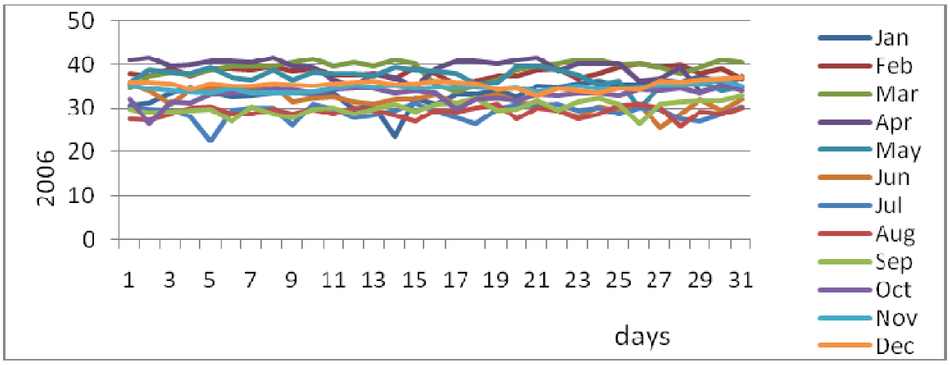


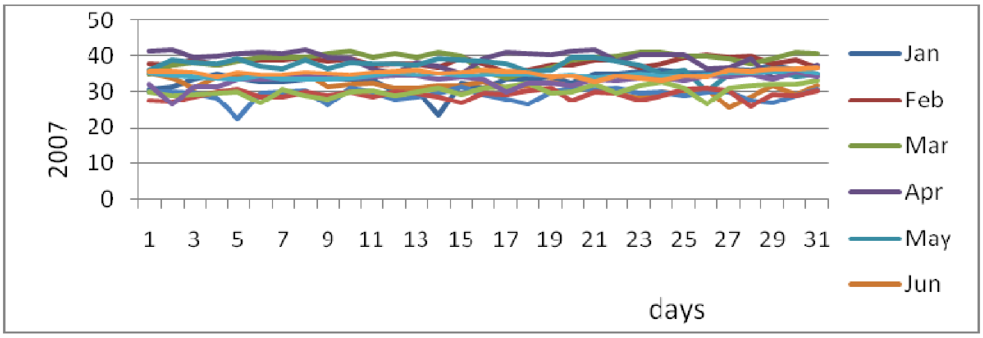


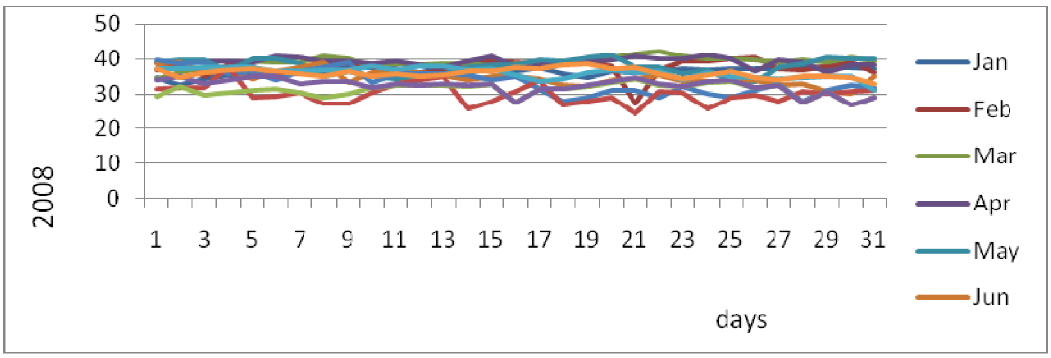
Noon max temperature data

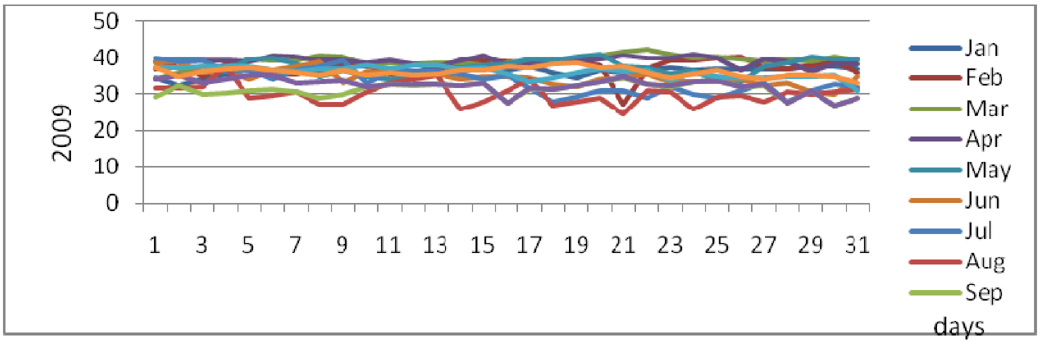
The noon maximum data of few years are shown on daily basis. These data are metrological records during the day time's 11a.m-5pm.







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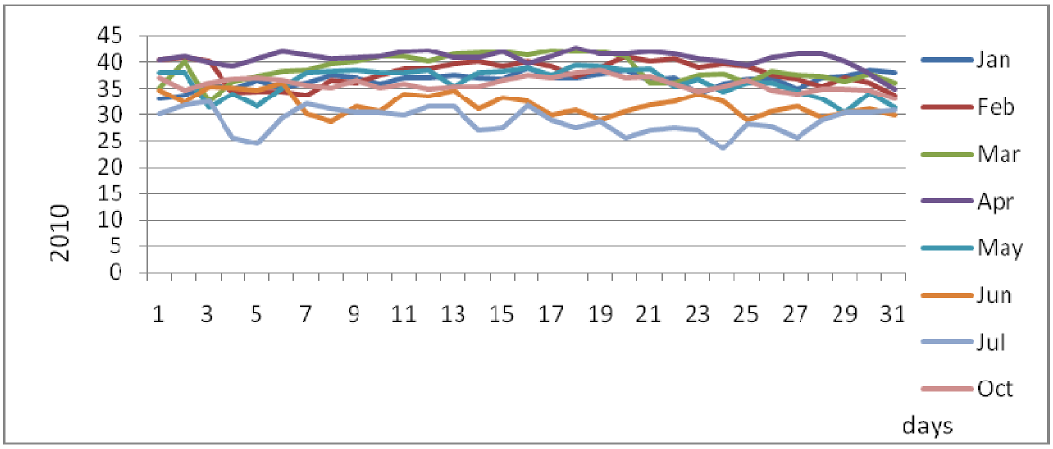
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ANNEX 5. Multifactor Combination Table

The factors: container size (1,1. 5, 2 litre), turbidity (<30, 30-60 and 90 NTU) and duration (1.5, 3, 4.5hours); and the response variable: Microbial mass load at each factor combination, with a factor level of 3, for each factor and the replicates (mean value is presented here).

Table 5.1 Microbial Test Result of the Month February

Container size	Turbidity	Duration	Microbial mass
-1	-1	-1	63
-1	-1	0	40
-1	-1	1	0
-1	0	-1	70
-1	0	0	38
-1	0	1	0
-1	1	-1	66
-1	1	0	40
-1	1	1	0
0	-1	-1	69
0	-1	0	42
0	-1	1	0
0	0	-1	70
0	0	0	30
0	0	1	0
0	1	-1	70
0	1	0	38
0	1	1	1
1	-1	-1	68
1	-1	0	40
1	-1	1	0
1	0	-1	72
1	0	0	40
1	0	1	0
1	1	-1	70
1	1	0	45
1	1	1	1.3

Table 5.2 Test result of the month January showing temperature achieved during the disinfection process.

Container size	Turbidity	Duration	Microbial mass	Temperature reached
-1	-1	-1	67	43
-1	-1	0	40	46
-1	-1	1	0	53
-1	0	-1	69	42
-1	0	0	42	45.6
-1	0	1	0	52.3
-1	1	-1	70	39.7
-1	1	0	45	45.8
-1	1	1	0.7	49.8
0	-1	-1	71	42.5
0	-1	0	48	45.2
0	-1	1	0	52.1
0	0	-1	72	41.4
0	0	0	37	45.2
0	0	1	0	51.9
0	1	-1	69	38.9
0	1	0	48	45.2
0	1	1	0.3	49.2
1	-1	-1	72	41.8
1	-1	0	49	44.7
1	-1	1	0	51.3
1	0	-1	71	40.5
1	0	0	53	44.8
1	0	1	0	50.8
1	1	-1	73	37
1	1	0	57	43
1	1	1	2	47.8

Table 5.3 Test result of the month February showing temperature achieved during the disinfection process.

Container size	Turbidity	Duration	Microbial mass	Temperature reached.
-1	-1	-1	63	43.8
-1	-1	0	40	47
-1	-1	1	0	54.2
-1	0	-1	70	42.5
-1	0	0	38	46
-1	0	1	0	53
-1	1	-1	66	40.5
-1	1	0	40	46.5
-1	1	1	0	51
0	-1	-1	69	43.8
0	-1	0	42	46.7
0	-1	1	0	53.5
0	0	-1	70	42.6
0	0	0	30	46.7
0	0	1	0	53
0	1	-1	70	40.9
0	1	0	38	46.3
0	1	1	1	50.8
1	-1	-1	68	42.6
1	-1	0	40	45.5
1	-1	1	0	52.3
1	0	-1	72	41.4
1	0	0	40	45.6
1	0	1	0	51.6
1	1	-1	70	39
1	1	0	45	44.7
1	1	1	1.3	50.8

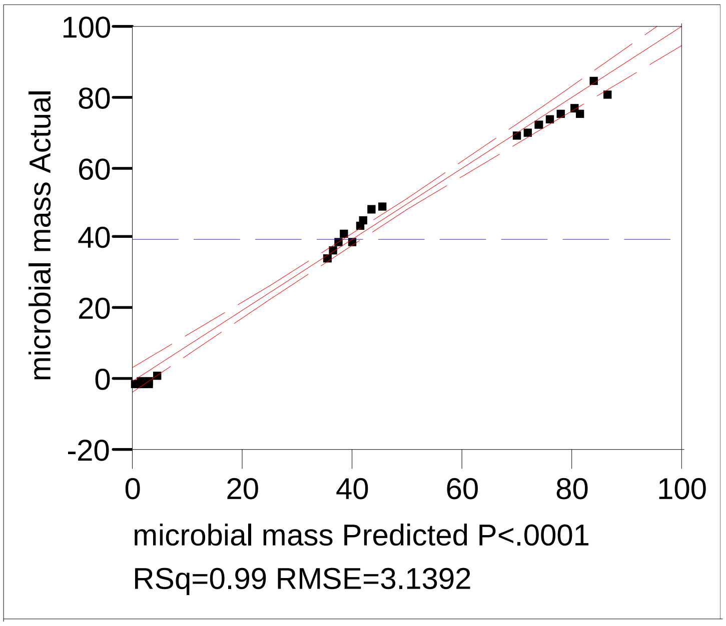
ANNEX 6. Statistical Analysis

The leverage plots showing the individual and combinative effects of the factors on the result obtained (response) in the first month January is presented as shown below. Similar plots are observed for the other month February with slight improvement in the nature of the plots but with similar an overall significant effect as that of January.

Response microbial mass

Whole Model

Actual by Predicted Plot



Parameter Estimates result

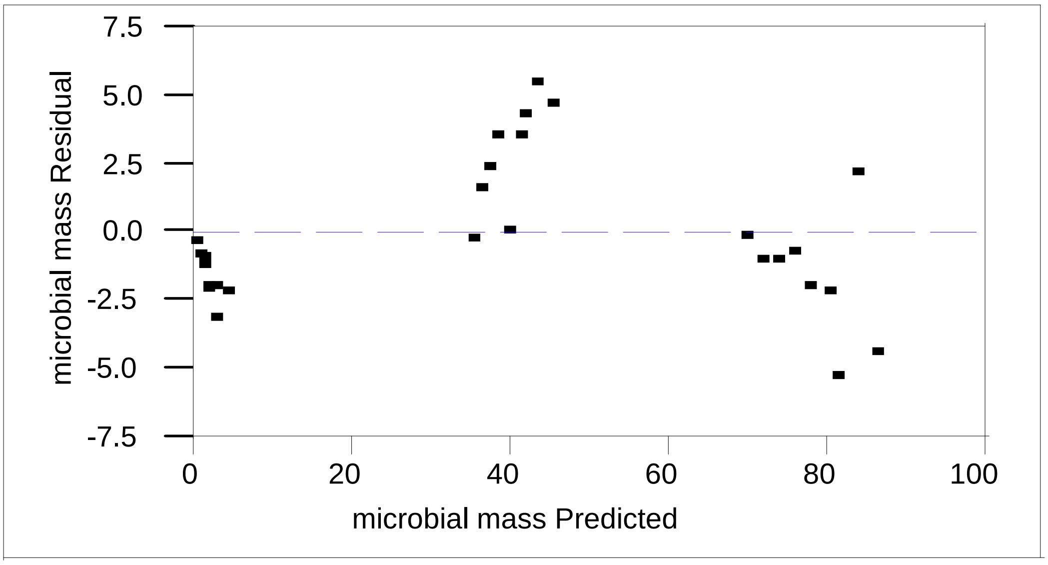
Term	Estimate	Std Error	t Ratio	Prob>|t|

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	39.814815	0.604145	65.90	<.0001
Container size	3.5388889	0.739923	4.78	0.0001
Turbidity	1.5	0.739923	2.03	0.0562
Duration	-38	0.739923	-51.36	<.0001
Container size*turbidity	0.3083333	0.906217	0.34	0.7372
Container size*duration	-2.358333	0.906217	-2.60	0.0170
turbidity*duration	-0.75	0.906217	-0.83	0.4177

Effect Tests

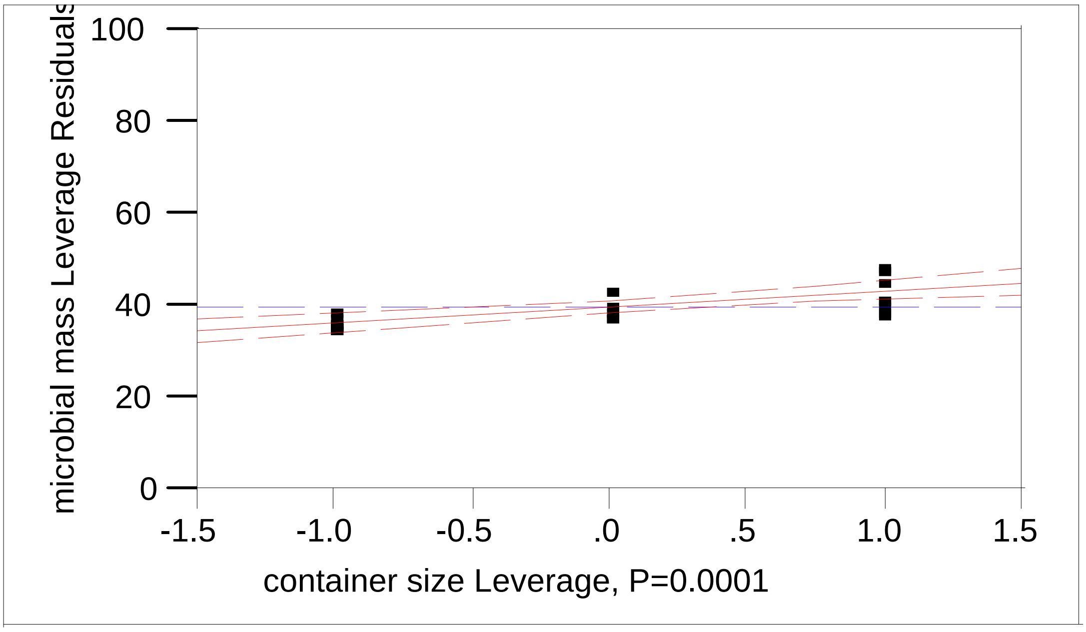
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Container size	1	1	225.427	22.8750	0.0001
Turbidity	1	1	40.500	4.1097	0.0562
Duration	1	1	25992.000	2637.507	<.0001
Container size*turbidity	1	1	1.141	0.1158	0.7372
Container size*duration	1	1	66.741	6.7724	0.0170
turbidity*duration	1	1	6.750	0.6849	0.4177

Residual by Predicted Plot



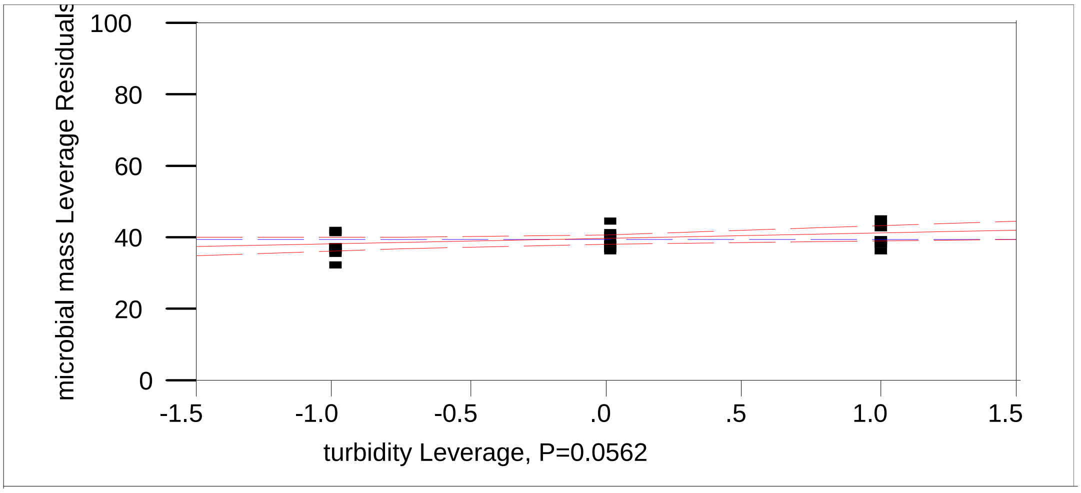
Container size

Leverage Plot



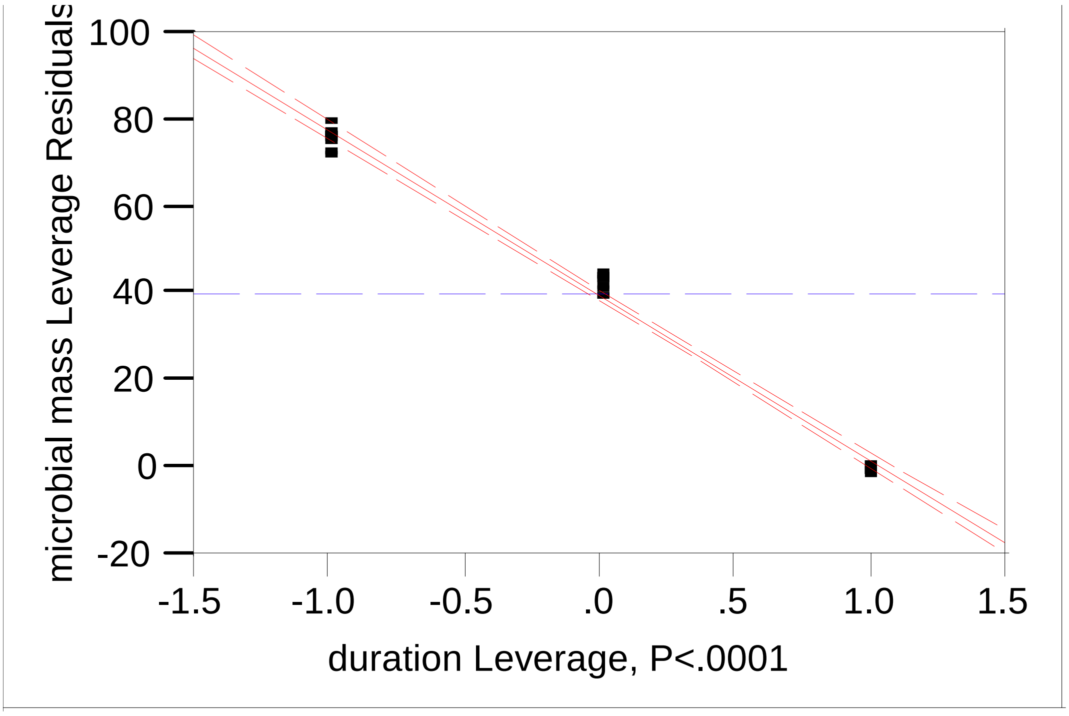
Turbidity

Leverage Plot



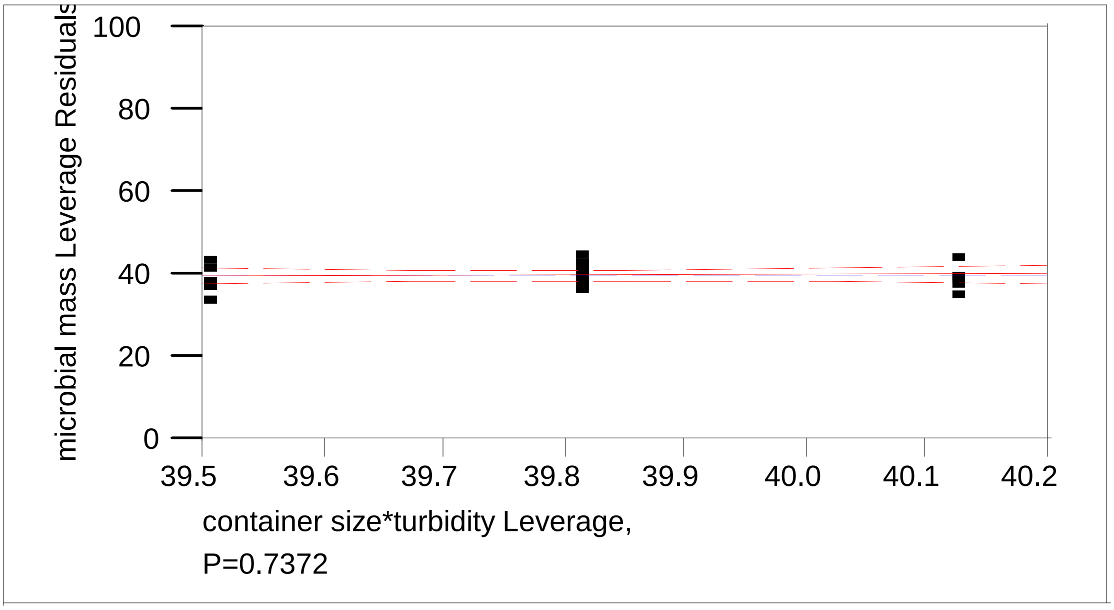
Duration

Leverage Plot



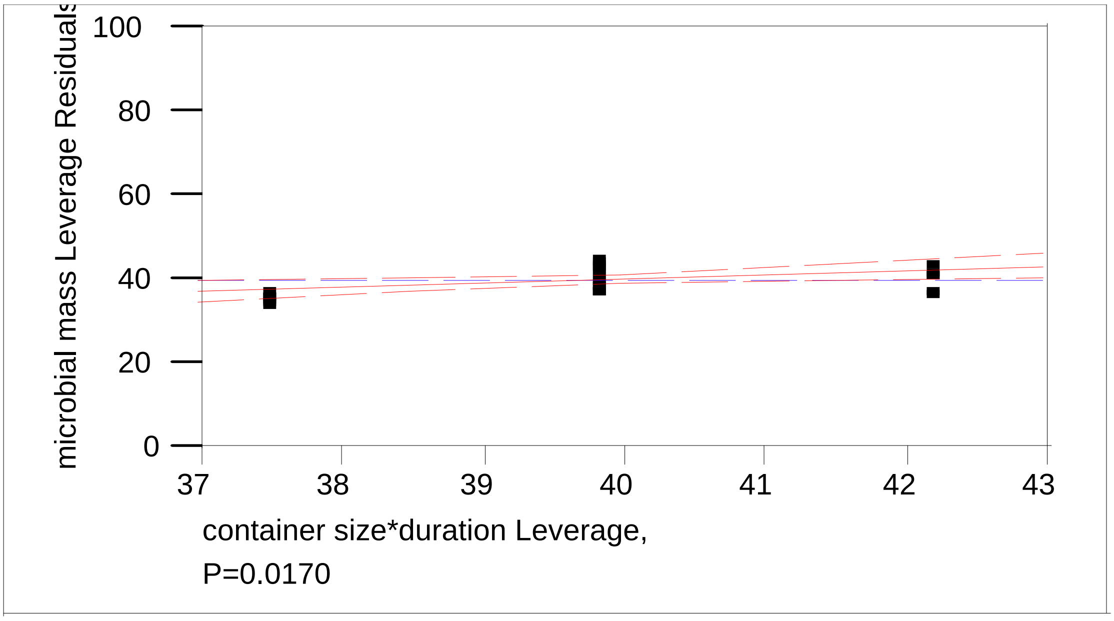
Container size*turbidity

Leverage Plot



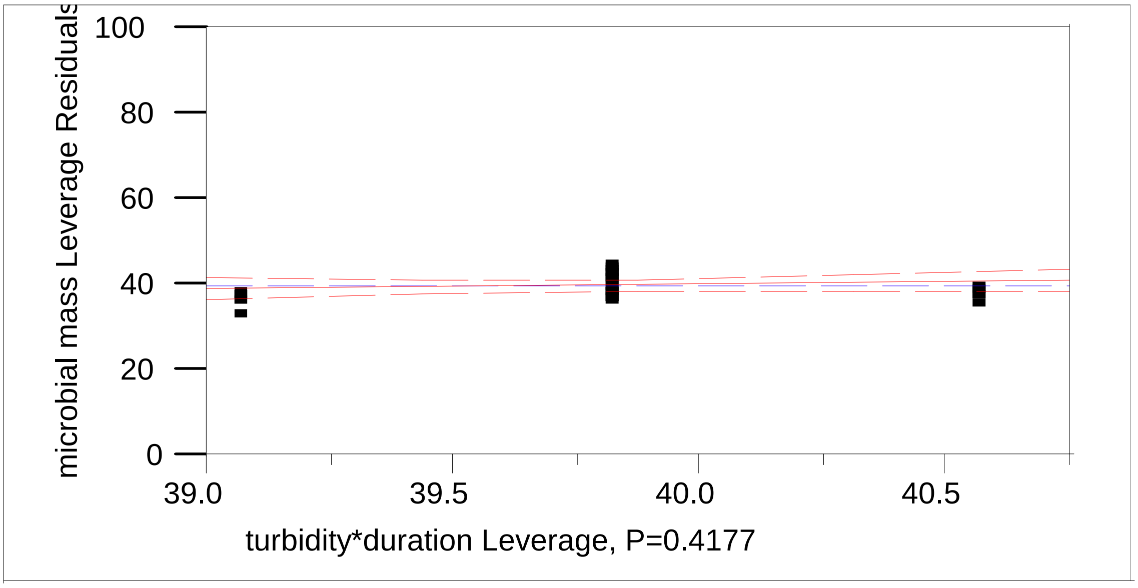
Container size*duration

Leverage Plot



Turbidity*duration

Leverage Plot



Therefore the overall model equation is:

$39.81+3.54X_1+1.5X_2-38X_3+0.31X_4-2.36X_5 -0.75X_6 =Y$

Where:

$X_1 =$ Container size (PET bottles)

$X_2 =$ Turbidity

$X_3 =$ duration

$X_4 =$ $X_1 * X_2$

$X_5 =$ $X_1 * X_3$

$X_6 =$ $X_2 * X_3$

Y = Response (microbial mass reduction)

Annex 7: **Annual Average daily radiation in kwh/m^2 per year at Woreda level (source: SWERA, 2007)**

Guba woreda in BGR