# KENYA NATIONAL ACADEMY OF SCIENCES

# NASAC LEOPOLDINA CAPACITY BUILDING GRANT

**with funding support from the German Federal Ministry of Education and Research (BMBF)**

## PROJECT TITLE:

## *"Point of Use Water Purification Technology for Sustainable Water in Africa"*

# Final report


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# Table of Contents

# LIST OF TABLES



# LIST OF FIGURES

## Narrative summary

The NASAC grant has contributed to capacity building, enhanced collaboration and extension of the mandate of the Kenya National Academy of Sciences (KNAS). KNAS has the overarching mission to mobilize the scientific community in the creation, maintenance, and advisement of knowledge in all fields of human endeavor, to effectively inform policy, build capacity in research and innovation and to provide solutions to improve the quality of life.

The project grant has contributed to KNAS's mission by strengthening the application of basic sciences to the economic, social and cultural development of Kenya. The results of the project have been disseminated in international conferences and workshop with the local communities. By sharing the results of the project with stakeholders in academia, local communities and policy makers, the project has contribute to the Kenya National Academy of Sciences (KNAS) in making the voice of African science heard with decision-makers and decision-makers worldwide. Furthermore, developing the point of use water technology for use by communities that do not have access to safe drinking water, the project has supported the KNAS in contributing to science and technology capacity building

In addition, the project has strengthened collaboration between the KNAS and the University of Nairobi. It has also provided the platform for enhanced collaboration between the University of Nairobi and Jaramogi Oginga Odinga University of Science and Technology, and offered opportunity for interaction with the local communities and the Government Agencies in Bondo District. This will go a long way in achieving one of the Academy's strategic objectives in establishing chapters in the new created county administration units so as to be able to inform policy.

The grant has also contributed to science and innovation. The scientific data generated from this project has shown the potential to reduce the solar disinfection exposure time from the prescribed 6 hours per day to only 2 hours when the water is treated with photocatalyst before exposure to sunlight. The findings of this research will be taken up to investigate the suitable design and conditions for the development of the point of use water purification systems to be used by the local communities.

# CHAPTER ONE

# 1.0 INTRODUCTION

## 1.1 Background

Kenya is categorized as a chronically water scarce country [World Bank, 2009], with a per capita water supply less than 647 $m^3$/person per year [Olago, 2009] compared to the Global benchmark of 1,000 $m^3$/person per year [Onjala, 2002]. Further statistics project a drop in water availability to 235 $m^3$/person per year by 2025[2]. Water quality posses an equally great challenge as water quantity. The total national population is about 38.6 million of which the rural population is approximately 26.13 million and urban population is 12.46 million. It is estimated that only 13.4% of the rural population and 38.4% of the urban population have access to treated safe drinking water. The occurrence of biological and chemical contamination renders the available scarce water resources unfit for human consumption [Wandiga, 2001]. However, due to lack of access to treated water, many people are compelled to drink untreated water exposing them to chemical and biological contaminants which have adverse health effects.

Water borne diseases are among the major killers in the country, especially among children [World Bank, 2008; Black *et al.,* 2001]. Studies into point of use water purification and disinfection seek to provide safe drinking water to the huge population that does not have access to safe drinking water. In addition, availability of safe drinking water will also contribute to achievement of the Kenya Vision 2030 and the millennium development goals targets related to safe drinking water. Supporting access to safe drinking water will also contribute to improving human health and poverty reduction as well as socio-economic development by reducing medical costs, and the amount of time lost due to illness causing hospitalization due to waterborne diseases.

The project sought to develop point of use water purification and disinfection technologies that can be adapted for use by the communities that have no access to treated water; support characterization of water quality; develop a purification strategy; disseminate the developed knowledge on point of use water purification to the stakeholders; and establish replication strategies for application of the developed technology in other parts of the country.

Specifically, the project will target development of low energy intensive and environmentally friendly technologies such as solar disinfection (SODIS) and related physical methods. In addition, synergistic effects in water disinfection will be investigated to optimize the performance of the developed technologies. In this regard, the project will seek application of physical methods, mild oxidative disinfection techniques and advanced novel oxidation technologies.

## 1.2 Objectives

### 1.2.1 Overall Objective

The overall objective of this proposal is to strengthen research in water management to solve societal and regional challenges in Africa. The results of this project will feed into the policy-makers' booklet on water management prepared under the NASAC-Leopoldina cooperation project.

### 1.2.2 Specific objectives

1) To strengthen research in water purification and disinfection in order to provide safe drinking water to people who have no access to treated water.

2) To investigate the use of Solar Disinfection technology in inactivation of biological water contaminants.
3) Investigate the potential by products and release kinetics in order to guide the public on application of the technology.

# CHAPTER TWO

## 2.0 Literature review

Despite the fact that good quality drinking water is vital for human health and development, about 1.1 billion people in the world lack access to safe drinking water [Sobey*et al.,* 2009]. In addition, more than 2.5 billion people do not have access to improved sanitation and directly or indirectly affect the water quality. Several water purification systems have been developed, but their application in developing countries is hampered by high installation or operational costs. Further, some technologies such as chlorination, ozonation, chlorine dioxide and chloramination produce disinfection by products DBPs [USEPA, 2012; Shannon *et al.*, 20108]. Recent studies show that DBPs such as trihalomethanes (THMs), haloacetic acids (HAAs), chloral hydrates (CH) among others in drinking or recreation water may cause toxicological effects to human health[Villanueva and Font-Ribera, 2012]. Our research group is involved in assessment of drinking water quality from different sources such as rivers, lakes and ground water resources. We are also focusing on development of low cost point of use water purification systems using locally available natural or synthetic materials with the goal of developing low cost and energy efficient point of use water purification systems.

Provision of safe drinking water to the entire global populationposes a great challenge to the Global community. According to UNICEF estimates, over one billion people do not have access to safe drinking water. This constitutes over 16% of the global population lacking access to safe water, thus exposed to a diversified range of biological and chemical contaminants. Diarrheal diseases are the fifth leading killer of human globally after chronic obstructive pulmonary disease, lower respiratory infections, stroke and coronary artillery disease [WHO, 2008]. Despite

the fact that diarrheal diseases can occur at any age, children seem to be the most affected. According to Black *et al.* (2003), diarrheal diseases account for approximately 2 million childhood deaths each year. The disease episodes are strongly associated with poverty and poor environmental hygiene conditions especially in developing countries. However, there are also scattered cases of waterborne diseases in developed and industrialised countries accounting for over 0.24 million deaths per year. The main causative agents of waterborne diseases are bacteria, protozoa and viruses. Although bacteria are reported to quickly succumb to disinfection treatments, some protozoa and viruses are much more resistant and are therefore commonly detected in both treated and untreated drinking water systems.

Chlorination has been the single most widely used disinfection method for over 10 decades. However, the emergence of disinfection by products such as THMs, chloroacetamides, haloacetic acids inorganic chloramines among others associated with chlorine has stimulated research in others methods in a search to minimize the formation of the large number of disinfection by products [Shannon *et al.*, 2008]. Consequently, methods using UV irradiation, ozone [Renneckeret *al*., 2001 and Kim *et al.*, 2002], chlorine dioxide, gamma irradiation [Frenget *al.*, 2011] as well as filtration based technologies have been developed. The main barriers encountered in application of these established technologies are associated with the high costs of installation and maintenance, socio-economic and environmental conditions. This has further led to development of solar irradiation based techniques such as SODIS, widely advocated in the developing countries due to the low costs involved. However, the effectiveness of SODIS in inactivating different types of waterborne pathogens has not been fully studied.

## 2.1 Statement of the problem

Chemicals and biological water contamination are the leading causes of water borne morbidity and mortality. Despite the fact that several conventional methods such as chlorination, chloramination, Ultra Violet, ozone, ultrafiltration have been developed can considerably eliminate or reduce the risks associated with waterborne pathogens, these methods suffer from one or more impediments which include: high costs of installation and maintenance, formation of disinfection by-products and resistance from different pathogens.

Currently, more than 1 billion people in the world do not have access to treated water. The highest percentage of the population without access to safe drinking water is in developing countries. The situation is further aggravated by lack of adequate and proper sanitation systems which contribute to increased load of bacteria and enteric viruses into the surface and underground water resources. Furthermore, poor handling of agrochemicals and industrial chemicals mostly in developing countries also contributes to release of high loads of toxic chemicals into the water resources. Furthermore, in some cases, treated water can undergo secondary contamination in the distribution system leading to the growth and development of diseases pathogens. This necessitates the application of point of use water purification systems to arrest the pathogenic organisms and other chemical contaminants before the water is consumed by the end users. This study investigated the potential to enhance Solar Disinfection of drinking water using locally available natural materials and synthetic inorganic photocatalysts.

# CHAPTER THREE

## 3.0Methodology

Chemical and mirobiological water contaminants were determined and characterized using standard methods. The purification strategies explored the use of physical and chemical methods using natural and chemical based materials. Natural plant materials include different local tea varieties and *moringaoleifera.* Synthetic and photocatalytic materials based ondoppedcpperphotocatalysts.

The raw water samples were treated from the river and exposed to different treatments and exposed to sunlight. Inactivation effects were monitored using 3M *E. Coli*Kits. The kits were spiked with 1 mL treated water samples and incubated at 37 $^{o}$C for 24 hours. Colon forming units were counted and used to calculate *E. Coli*and total coliform concentrations.

### 3.1 Testing seasonal effect on coliforms load in the raw water samples

Water samples were collected during the wet and dry seasons. The samples were divided into 500 ml portions and transferred into transparent PET bottles. The bottles were grouped into duplicates for different experiments: Sunlight, photocatalyst, control, laboratory setup, and temperature and pH measurements (Table 3.1).

***Table 3.1: Experimental design for disinfection experiments***

| Time (hrs) | Raw water-exposed to sunlight | Water treated with Photocatalyst-exposed to sunlight | Control-covered in aluminium foil | Temperature measurements-exposed to sunlight | pH measurements - exposed to sunlight |
|---|---|---|---|---|---|
| 0 | | | | | |
| 2 | | | | | |
| 4 | | | | | |
| 6 | | | | | |

Figure 3.1 summarises the experimental setup for different tests showing samples exposed to sunlight, water treated with photocatalyst, control (covered), and samples for temperature and pH measurements.

***Figure 3.1 Experimental setup for testing disinfection process under sunlight.***

## Investigation of optimal time for disinfection using synthetic photocatalyst.

Tests for optimal time for photocatalytic solar disinfection included duplicate bottles for raw water exposed to sunlight, water treated with photocatalyst, control samples (covered), temperature and pH samples. The samples were monitored for coliforms every 30 minutes from the beginning (at time t = 0 minutes) up to the 6 hours. Every 30 minutes, 1 ml aliquot sample was taken from each bottle and spiked onto the 3M Ecoli KIT. The spiked kit was incubated for 24 hours. After incubation, the colon forming units (CFU) were counted for Ecoli and other coliforms.

***Table 3.1: Experimental design for investigating optimal disinfection time***

| Time (mins) | Raw water- exposed to sunlight | Water treated with Photocatalyst- exposed to sunlight | Control- covered in aluminium foil | Temperature measurements- exposed to sunlight | pH measurements - exposed to sunlight |
|---|---|---|---|---|---|
| 0 | | | | | |
| 30 | | | | | |
| 60 | | | | | |
| 90 | | | | | |
| 120 | | | | | |
| 150 | | | | | |
| 180 | | | | | |
| 210 | | | | | |
| 240 | | | | | |

# CHAPTER FOUR

# 4.0 Results and Discussion

## 4.1 Results

We have established data on water disinfection using locally available materials from different type of teas used locally in the country. The investigation using green tea, black tea and lemon grass as alternative disinfection materials have yielded results summarized below.

## 4.2 Total coliforms in raw water

Analysis of coliforms in raw river water revealed high concentration of *E. Coli*and other coliforms.The average *E. Coli* concentration was 315 colon forming units (CFU/ml), other coliforms 45 CFU/ml, whereas total coliform concentration was 353 CFU/ml (Figure 4.1). These levels were higher than the WHO guideline for drinking water which is 0 CFU/100 ml for *E. Coli.*

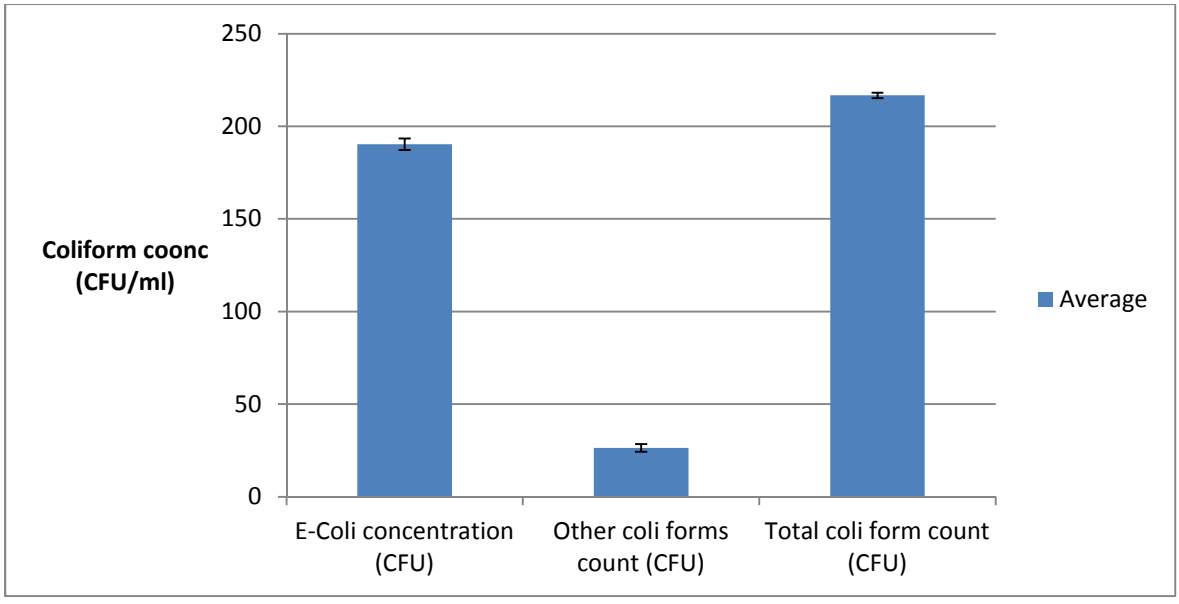


**Figure 1: Concentration of E-Coli and other coliforms in raw water**

The high load of coliforms in the water samples confirm the need to address need for point of use water purification systems to provide water to the local communities that have no access to safe drinking water.

## 4.3 Testing the use of different tea extracts to inactivate *E. Coli* and other coliforms in water

Black tea, green tea and lemon grass were tested for their ability to inactivate *E. Coli*and other coliforms in the raw water. Aqueous extracts of the three types of teas that used locally in Kenya revealed different capacities to disinfect coliforms from the water samples.

**a) Black Tea:**

70% reduction in *E-coli*was observed for water treated with black tea extract, reducing concentration from 191 CFU/ml to 58 CFU/ml: Other coliforms concentrations remained relatively high in water exposed to black tea extracts, achieving reduction from 27 CFU/ml to 18 CFU/ml which represented 33% reduction in the concentration of other coliforms. This is illustrated in Figure 4.2 below.

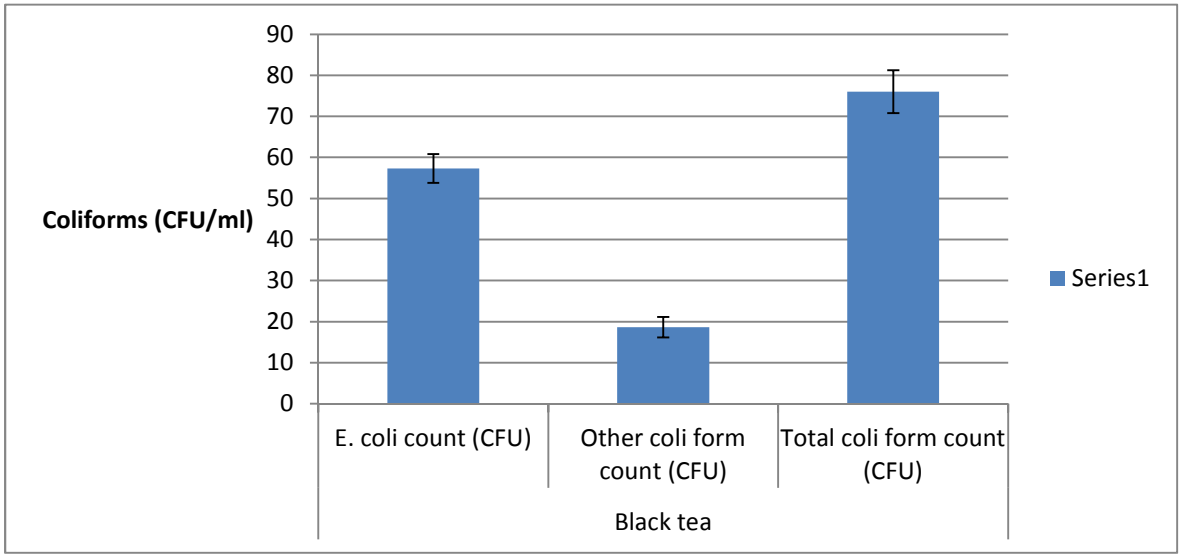


***Figure 4.2: Effect of black tea on E-Coli and other coliform in drinking water***

***b) Green tea:***

Raw water treated with aqueous extract of green tea exhibited 100% *E. coli* inactivation within the 30 minutes exposure period. However, the effect of aqueous extract of green tea on other coliforms was less compared to *E. Coli.* The concentration of other coliformsin water was 9 CFU/ml representing 66% reductionafter exposure of the water to green tea extract for the same period as for *E. Coli*(Figure 4.3).

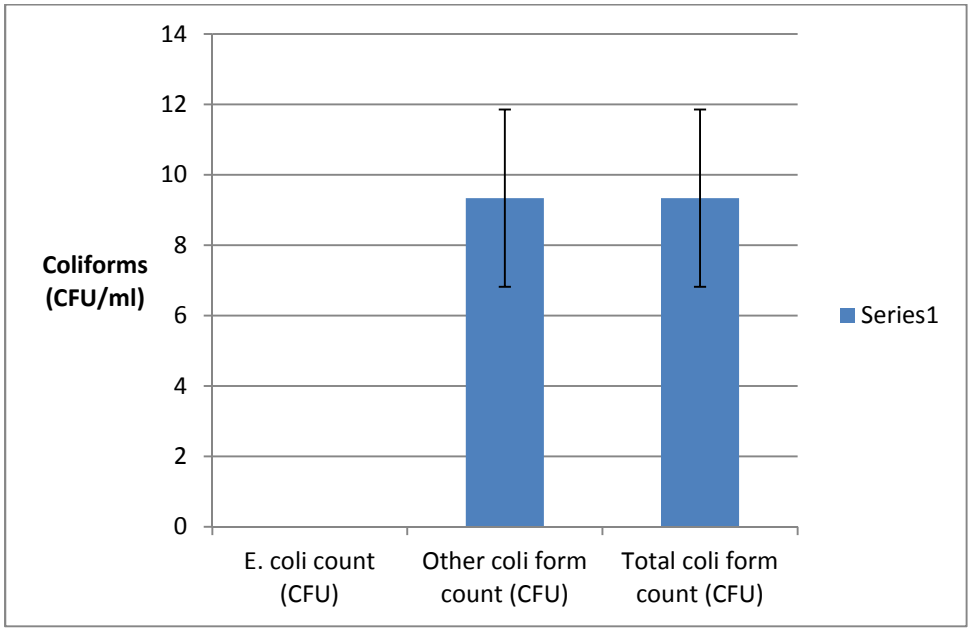


***Figure 4.3 Effect of green tea on E-Coli inactivation in drinking water***

**c) Green tea and Lemon grass**

Varying concentration of tea extracts achieved different degrees of inactivation of *E. Coli*in raw water. Black tea showed the lowest inactivation effect with 70%*E. Coli*inactivation for a 40% solution. Concentrations of green tea above 10% were observed to remove 100% of *E. Coli.* (Figure4.4 top), whereas Lemon grass recorded 100% inactivation for all coliforms with concentration of 1% (Figure4.4 bottom). The data reveal that lemon grass is more effective at inactivating both *E. Coli*and other coliforms than the green tea and black tea. Back tea is the least

effective in inactivation of the coliforms.This results agree with the ealier study by Archana and Abraham [2011] who found higher antimicrobial activity for green tea than black tea. However, the extention of the work to water disinfection has not been carried out, neither studies on application of lemon grass been carried out.

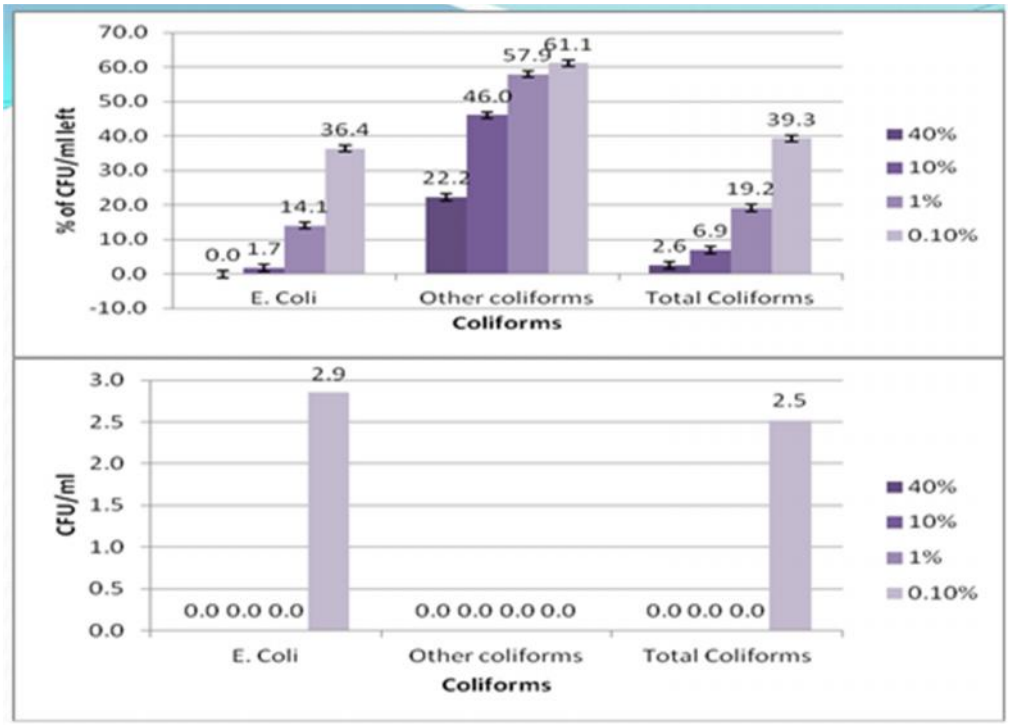


***Figure 4.4 Green teaand lemon grasson coliform inactivation effects***

## 4.4Comparison of E. Coli Inactivation using SODIS and copper based photocatalyst

In testing the potential to enhance solar disinfection (SODIS) the study exposed the application of copper based photocatalyst. Application of 10 mg of the photocatalyst into 500 ml of the raw water achieved 100% inactivation of *E. Coli*inactivation in less than four hours compared to SODIS alone which achieved 97% *E. Coli* removal after six hours under the same conditions (Figure 4.5). The control experiments with raw water in PET bottle that had been wrapped in

aluminium foil achieved less than 10% *E. Coli* removal. The fast inactivation observed in the water treated with the treated water could therefore be attributed to photacatalytic effect of sunlight on copper which accelerated inactivation of *E. Coli* in the water.

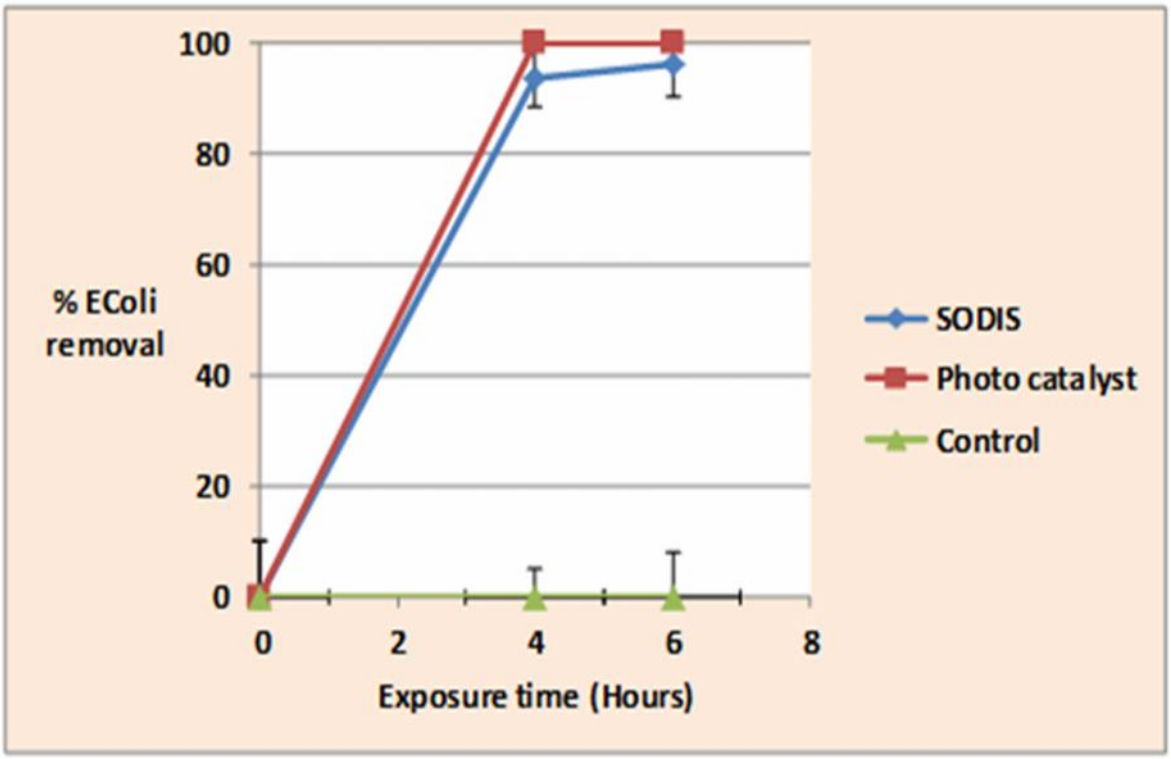


***Figure 4.5 Comparison of E. Coli inactivation by SODIS and Copper Based Photocatalyst***

## 4.5Comparison of E Coli inactivation during wet and dry seasons

Water collected during the wet and dry seasons revealed different loads of *E. Coli*, with the highest concentration of *E. Coli* detected in wet season samples. This suggests increase in fecal coliform load due to runoff from the residential areas during the rainy season. Figure 4.6 shows that inactivation of *E.Coli*using the photocatalyst was completed in less than four hours, whereas SODIS required more than six hours for complete inactivation. The control experiment achieved

less than 50% inactivation in the six hours of exposure.

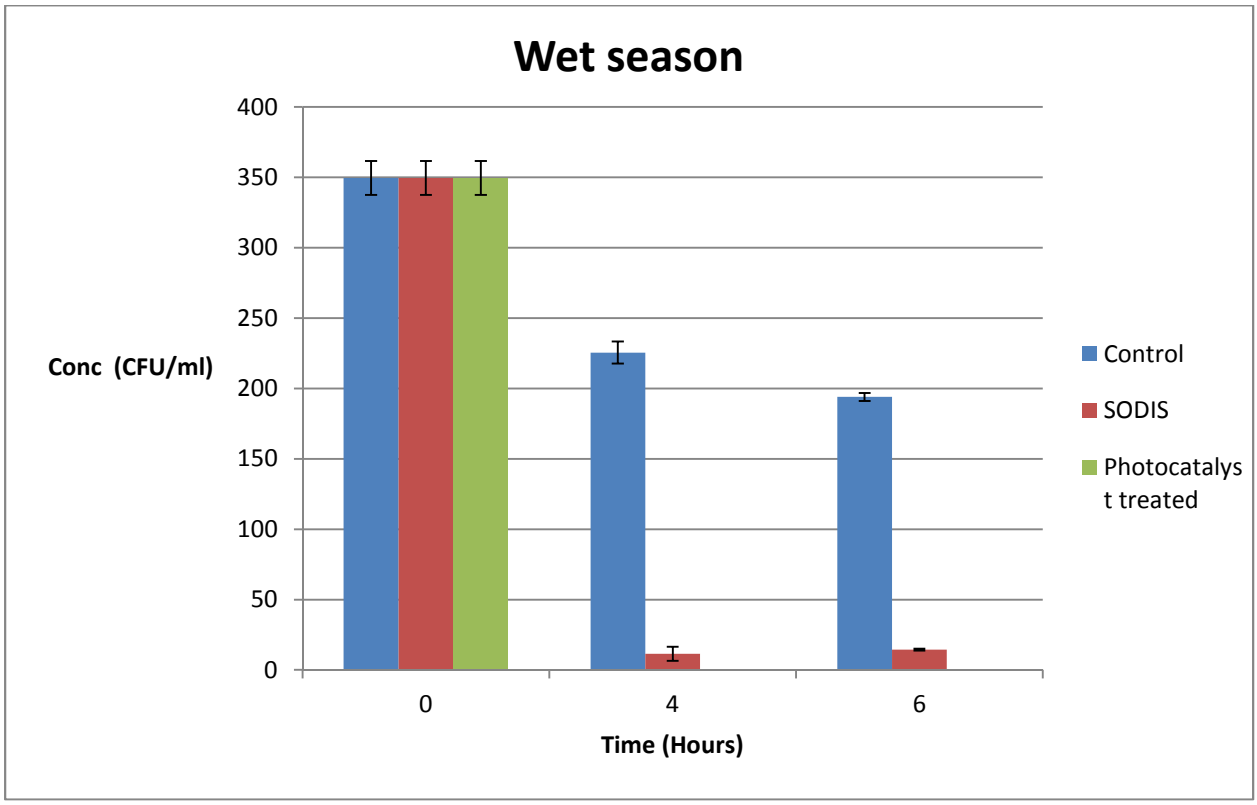


***Figure 4.6 E. Coli inactivation in the wet season water samples***

Figure 4.7 illustrate lower levels of *E. Coli* in the water samples collected in the dry season. Inactivation rates were also relatively faster compared to the wet season samples. For dry season samples, 100% *E. Coli* removal was achieved within 6 hours compared to the wet season samples which required more than six hours. The faster rates observed in inactivation of *E. Coli*in water collected in the dry season could be attributed to low turbidity of the water that enhanced light penetration.

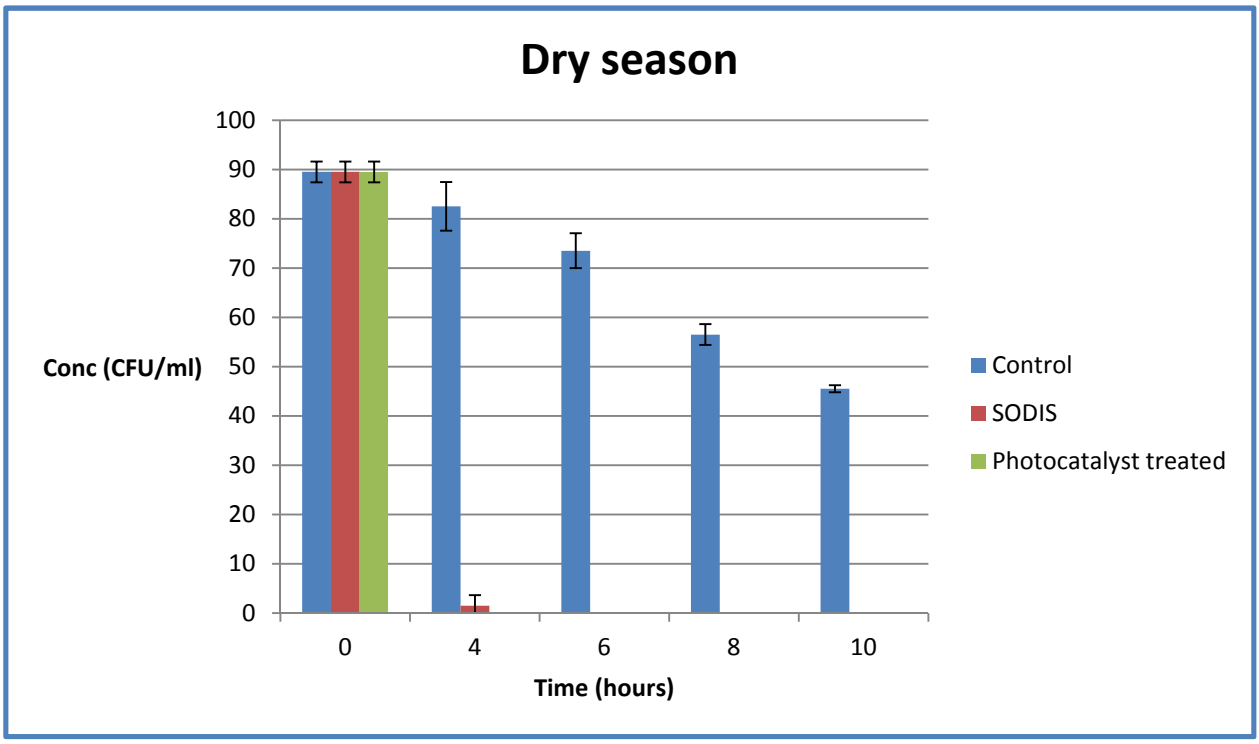


***Figure 4.7 Inactivation of E. Coli in river water during dry season***

## 4.6 Investigation of optimal time for inactivation of *E. Coli*in river water

Optimal inactivation time was investigated by collecting aliquot samples every 30 minutes and testing for *E. Coli* load remaining in the water. The data revealed that 120 minutes were adequate for complete removal of *E. Coli* from the water samples treated with the photocatalyst. On the other hand, water exposed to sunlight without addition of the photocatalyst required at least 240 minutes to completely remove *E. Coli* from the water (Figure 4.8). The control sample that had been completely covered from sunlight achieved less than 10% *E. Coli* removal in 240 minutes.

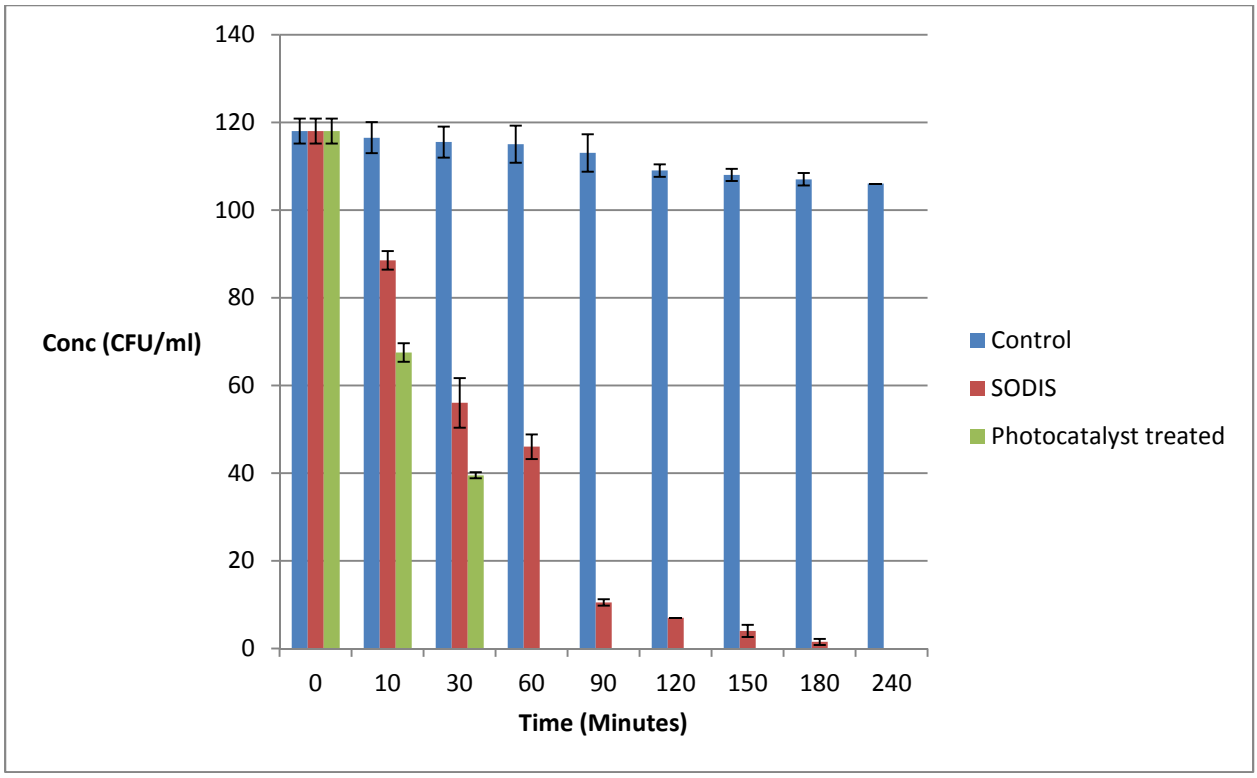


***Figure 4.8 Optimal time for Inactivation of E. Coli***

## 4.7 Inactivation of other coliforms

Figures 4.8 and 4.9 illustrate the concentrations of other coliforms in the water during the wet and dry seasons. Unlike the trend observed for *E. Coli*, it was noted that other coliform concentrations were relatively uniform in both wet and dry season compared to the trend observed for fecal coliforms which had significantly higher levels of *E. Coli in the wet season than the dry season*. However, inactivation kinetics seems to follow similar trend for both cases, with slower inactivation rates observed for the samples collected in the wet season compared to the dry season samples. This could be explained by higher water turbidity in wet season samples compared to the dry season samples. Unlike the case of *E. Coli*inactivation, both SODIS and photocatalyst treated water required more than 6 hours for complete removal of the other coliforms (Figure 4.9).

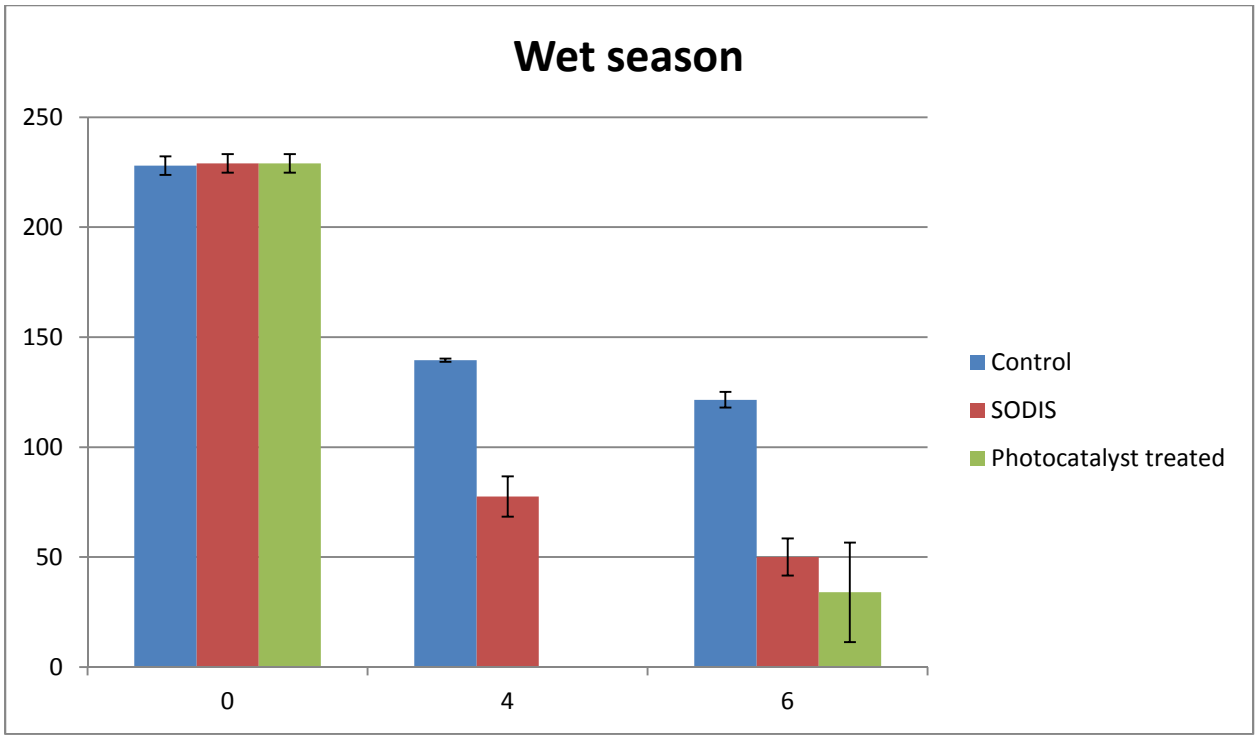


***Figure 4.9 Inactivation of other coliforms in river water during wet season***

For the samples collected during the dry season, inactivation of coliforms was completed within the six hours for both SODIS and photocatalyst treated water (Figure 4.10).The control samples achieved less than 50% coliform removal after 10 hours of exposure, suggesting a strong effect of solar radiation on inactivation of the coliforms. Inactivation rate was fastest for photocatalyst treated water followed by SODIS, and slowest in the water in the PET bottles covered with aluminium foil to block sunlight.

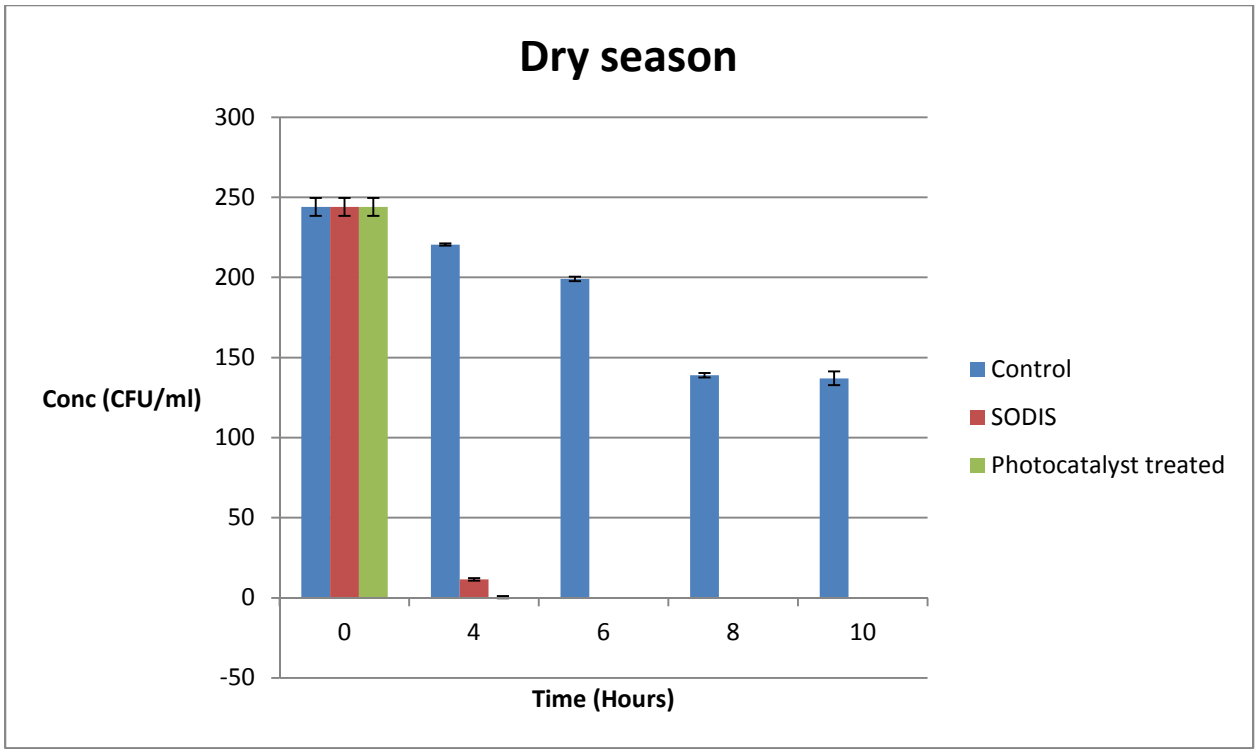


***Figure 4.10 Inactivation of other coliforms in river water during dry season***

Investigating optimal time duration for inactivation of other coliforms revealed fastest rate in water treated with the photocatalyst, followed by SODIS and lastly the control samples (Figure 4.11). 90 minutes was established as the optimal time for complete inactivation of coliforms in the water treated with the photocatalyst, whereas SODIS samples required more than 240 minutes to remove coliforms in the water. There was minimal inactivation of coliforms in the control samples, achieving <10% inactivation in 240 minutes (Figure 4.11).

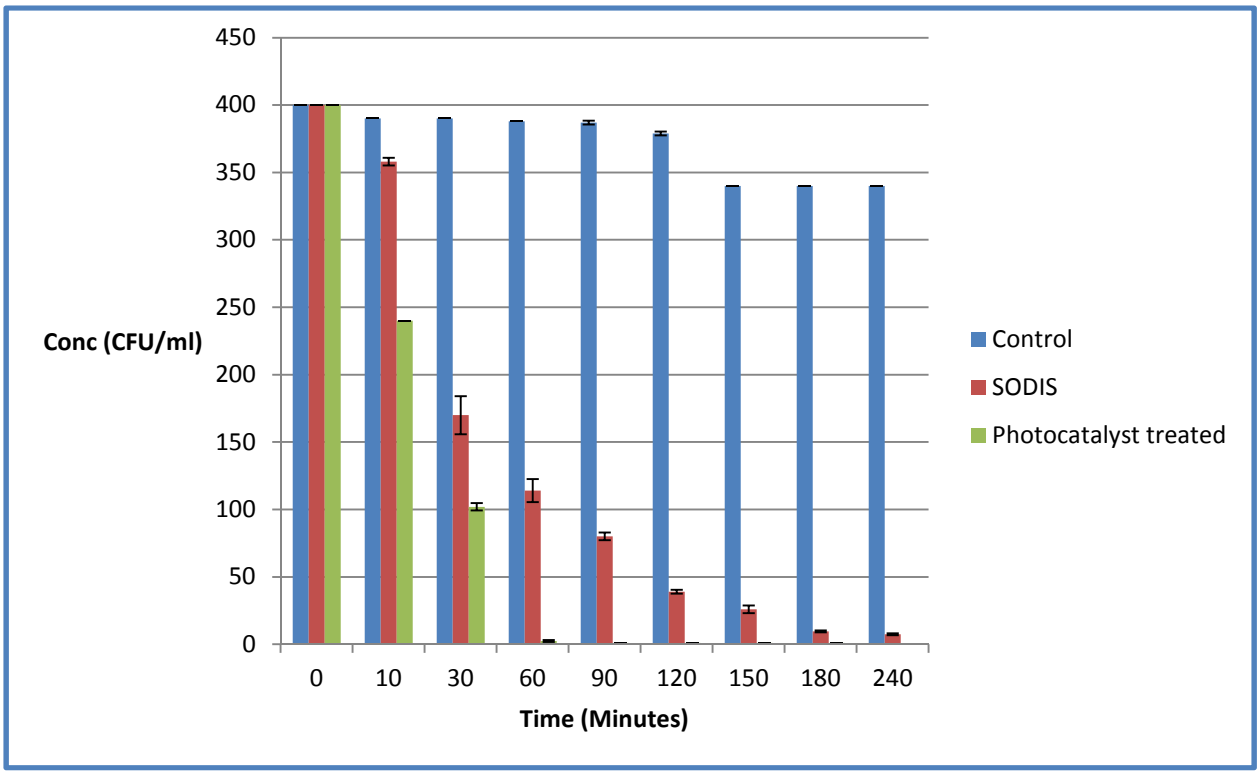


***Figure 4.11 Optimal time for inactivation of other coliforms***

## 4.2Discussion

The preliminary data sets show that lemon grass has higher *E. Coli*inactivation effect compared to green tea and black tea which have been reported in earlier studies[5]. Black tea is usually produced by fermentation process which reduces antibacterial effect. The use copper based photocatalysis enhanced inactivation of *E. Coli*compared to SODIS alone.

# CHAPTER FIVE

# 5.0 Conclusion and Recommendation

## 5.1 Conclusion

The study has demonstrated high prevalence of bacteriological water contaminants in both wet and dry seasons.

Both natural and synthetic materials have been tested for water disinfection potential with lemon grass *E. Coli*inactivation rates greater than the green tea and black tea. Varying concentration of tea extracts achieved different degrees of inactivation of *E. Coli* in raw water. Black tea showed the lowest inactivation rates with only 70%*E. Coli*inactivation at 40% v/v solution. Green tea at 10% v/v achieved 100% of *E. Coli.* Removal,whereas Lemon grass recorded 100% inactivation for all coliforms with concentration as low as 1% v/v.

The application of copper based photocatalyst showed promising results to enhance the rate of *E. Coli*inactivation in the raw river water samples compared to the effect of solar disinfection alone. The study established that 120 minutes exposure of raw water could completely inactivate E. Coli in the raw water treated with the photocatalyst.

This project has contributed to NASAC's mission by providing results that are valuable both to the NASAC-Leopoldina cooperation – as input to the policy-makers' booklet on water management – and NASAC's work in the area of water management in general. By sharing the results of the project with stakeholders in academia and policy makers, the project will contribute to building the capacity of the Kenya National Academy of Sciences (KNAS) in making the voice of African science heard with African decision-makers and decision-makers worldwide. This will also increase the visibility and relevance of the KNAS.

Furthermore, developing the point of use water technology for use by communities that do not have access to safe drinking water, the project will support the KNAS in contributing to science and technology capacity building.

### 5.2 Recommendations

Further studies are going on to establish the effects of different environmental conditions on inactivation kinetics. This should include changes in water pH, turbidity, solar radiation intensity and dissolved solids.

Testing effect of photocatalyst loading on inactivation kinetics of *E. Coli* and other coliforms in the raw water.

Further work should be carried out to investigate the mechanism of inactivation by the lemon grass and the photocatalyst on *E. Coli*.

Additional experiments should be conducted to test the potential of the photocatalystto removal chemical contaminants from the raw water samples.

Further work be carried out to investigate the appropriate design of the point of use water purification system for application at community level.

## 6.0 Acknowledgement

We would like to thank the NASAC, the Leopoldina and the German Federal Ministry of Education and Research (BMBF) for the grant that supported this work.

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## Annex: Plates