WATER QUALITY VARIATION AND POLLUTANTS TRANSFORMATION IN THE NADOSOITO DAM OF ARKATANI VILLAGE, MONDULI DISTRICT

Naziel Eliakimu

A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master's in Environmental Science and Engineering of the Nelson Mandela African Institution of Science and Technology

Arusha, Tanzania

February, 2019

ABSTRACT

The study aimed at assessing seasonal dynamics of water quality parameters, transformation of selected pollutants and seasonal diversity of selected microorganisms (Cyanobacteria) in Nadosoito dam of Arkatani Village, Monduli district, Arusha Tanzania. The study aimed at establishing the treatability of the dam water using Inclined Plate Settler (IPS) coupled with settling tank and a constructed wetland, from January to September 2017 capturing the wet months and the driest month. Analysis was carried out as per standard methods for the examination of water and wastewater (APHA 2012). High values of COD, from <0.7 to 87 mg/l, and turbidity, from 204 to 53 300 NTU, were recorded. Turbidity and TSS were highest at the onset of rainfall, and generally declined from the wet to the dry season. The highest levels for both were due to loading materials into the dam. Ammonia concentrations ranged from 0.14 to 270 mg/l and nitrate-nitrogen from 0.6 to 1715 mg/l; they were highest towards the end of wet season in april, while NO_2-N was highest (290 mg/l) in the dry season (September). There was a notably high value of Phycocyanin (PC) pigment (19.85 to 495 µg/l) unique to cyanobacteria, well above the WHO alert level of 30 µg/l. PC is associated with a variety of toxins affecting humans and animals. Possible sources of pollutants include; animals' droppings/urine and runoff from farms applying fertilisers. The results of this study suggest that water treatment systems must be designed to take care of the worst influent water quality conditions.

DECLARATION

I, **Naziel Eliakimu** do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this is my own original work, and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Naziel Eliakimu _____________ __________________

Name and signature of candidate **Date**

The above declaration is confirmed

Prof. Karoli N. Njau ____________ _________________

Name and signature of supervisor (1) **Date**

Dr. Revocatus L. Machunda _________________ _________________

Name and signature of supervisor (2) **Date**

COPYRIGHT

CERTIFICATION

The undersigned certify that they have read and hereby recommend for examination of a dissertation entitled; **Water Quality Variation And Pollutants Transformation In The Nadosoito Dam Of Arkatani Village, Monduli District**, to be accepted in partial fulfillment of the requirements for the Degree of Master of Environmental Science and Engineering of the Nelson Mandela African Institution of Science and Technology Arusha, Tanzania.

______________________________ __________________

Prof. Karoli N. Njau Date

______________________________ __________________

Dr. Revocatus L. Machunda Date

ACKNOWLEDGEMENT

I would like to thank the almighty God for His guidance toward the accomplishment of this work, without Him this work would have not been possible.

Secondly, I would like to thank my supervisors Professor Karoli N. Njau and Dr. Revocatus L. Machunda who tirelessly directed me and advised me until the accomplishment of this research. I have learnt a lot of things from them as supervisors, leaders and as persons, which have transformed my thinking as a researcher and as a person, may God bless you all.

Thirdly, I would like to thank my sponsor BG/ Shell for funding my research to its completion. The support of the VLIR-OUS program in field and laboratory activities is acknowledged gratefully.

I would like to acknowledge my colleagues in Nelson Mandela African Institution of Science and Technology that helped in different ways to make this work a reality; Jovine Malago, Paschal Chrisogoni, Debora Mahushi, Haruni Kidungu, Pantaleo Peter, Fr. Silvanus Mringi, Justine Lwekoramu and Paulo Sanka.

DEDICATION

This work is dedicated to my loving mother Magdalena Samwel Mbwambo, my son Solomon Elisha Kilupi and my goddaughter Dorothea Jeremiah, I love you! And, to my late father who always believed in me and said that I can do anything I want to, I will always love you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

APHA	American Public Health Association
BOD	Biological Oxygen Demand
CFU	Colon Forming Units
COD	Chemical Oxygen Demand
COSTECH	Commission for Science and Technology
DO	Dissolved Oxygen
EC	Electrical Conductivity
EPA	Environmental Protection Agency
FC	Feacal Coliform
Fe	Iron
IPS	Inclined Plate Settler
NM-AIST	Nelson Mandela African Institution of Science and Technology
NTU	Nephelometric Turbidity Unit
PC	Phycocyanin
SCA	Sydney Catchment Authority
SRP	Soluble Reactive Phosphorus
TANAPA	Tanzania National Park
TBS	Tanzania Bureau of Standards
TISAB	Total Ionic Strength Adjustment Buffer
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
TZS	Tanzania Standards
USA	United States of America
USEPA	United States Environmental Protection Agency
UV	Ultra Violet
WHO	World Health Organization
WSSCC	Water Supply and Sanitation Colaborative Council

CHAPTER ONE

INTRODUCTION

1.1 Background

Despite the clearly known importance of water to human life, it is currently estimated that 1.1 billion people in the world lack access to improved water supplies and 2.6 billion people lack adequate sanitation. This result in the global health burden associated with an estimated 4000–6000 children dying each day from diseases associated with lack of access to safe drinking water, inadequate sanitation and poor hygiene (UNICEF *et al*., 2004; WSSCC, 2004). In Tanzania, especially in the semi-urban to rural areas people use the contaminated water from different sources (rivers, water, dams etc.) due to limited options (Mohamed *et al.*, 2016). Arkatani village in Sepeko ward being in a semi-arid area is faced with a water scarcity, and the available water (Nadosoito dam – a major source), is faced with the water quality issues which change through the year. This study intended to assess the seasonal dynamics of water quality and transformation of pollutants and microbial diversity in the dam.

The dam is highly important to Arkatani and the surrounding villages. The study by Mtavangu (2015) indicates that, the turbidity of the dam is >1000 NTU in most time of the year. High turbidity harbours microorganisms including pathogens thus posing a risk to human health (Senay *et al*., 2002). The seasonal changes make the water less palatable and unfit for domestic use, and it is also reported to affect livestock. The dam is reported to be heavily polluted, and this makes it a breeding site of waterborne diseases such as diarrhoea, dysentery, salmonella, typhoid fever, and cholera (IPP Media, 2016). Despite the water's characteristic turbidity, the dam is shared by humans, livestock and wild animals, making it a potential source of zoonotic diseases. This also has the potential to add nutrients and organic matter when the animals drink from the dam.

Many scholars e.g. Vaishali and Punita (2013) explains that, waters with high total dissolved solids (TDS) contents are unpalatable and potentially unhealthy. Villagers admit that water situation in the area is terrible and the situation worsens during dry season. Villagers also reported animal deaths in certain periods of the year (Kurunju, M. Personal communication, 2016). Studies have established that, some freshwater cyanobacteria are known to produce potent toxins while other cyanobacteria species produce compounds causing unpleasant taste and odour (SCA, 2010). Francis (1878) made the first report of cyanobacterial poisoning, which led to the deaths of cattle, sheep, dogs, horses and pigs after they drank water contaminated with cyanobacteria in Lake Alexandrina, Australia. Since then many cases of farm animals, waterfowl and wild animals being poisoned by cyanobacterial water after swimming or drinking have been reported (Carmichael, 1994; Paerl, 1998; SCA, 2010; Mbukwa *et al*., 2013). The deaths of cattle reported in the Nadosoito dam could well be associated with the presence of cyanobacteria in the water.

In order to tackle the problem of high turbidity and produce potable water at Arkatani and other rural communities, current study by Nelson Mandela African Institution of Science and Technology (NM-AIST) has developed and tested innovative technology of combining settling tanks with Inclined Plate Settlers (IPS) and wetland. The system has shown to be feasible and effective to reduce the turbidity to drinking water standard levels. There is now a project to validate the technology to treat highly turbid water in the field environment of Nadosoito dam. As part of this project, monitoring was done during the research, on the dam water condition.

Equally important, the importance of this dam for domestic use and livestock and the deteriorating water quality with season, prompted the study to understand the variation of water quality, selected microorganisms and transformation of selected pollutants (NO_3-N, Nitrite-Nitrogen, NH_3-N, Phosphate, Iron) in the dam. The transformations occur through nitrification and desorption of phosphorus in water which are influenced by physico-chemical properties of water (Hao and Martinez, 1998; Polak and Kentzer, 2004). The study conducted provides guidance to develop measures to deal with the worsening situation so as to safeguard human health throughout the year. It is important to have information on water quality and pollution sources when one needs to implement the strategies for sustainable water use management (Sarkar *et al*., 2007; Zhou *et al*., 2007; Bu *et al*., 2009). Therefore, it is important to complete the study because data obtained will provide useful scientific information on the seasonal variation of dam waters and potential for growth of cyanobacteria and thus necessary information to guide the design and operation of the integrated IPS and other treatment systems to be installed at Nadosoito dam and other areas with similar properties.

1.2 Problem Statement and Justification

Pastoralists in semi-arid and arid areas face a problem of water scarcity for domestic and livestock. They also face reduced quality of available water. In Nadosoito, the major source of water that provides for domestic and livestock is the Nadosoito dam. The dam water is characteristically turbid with very fine clayey particles, which settle slowly. Community around Nadosoito have reported seasonal changes in the colour, odour and taste of the water in the dam, also some cattle mortalities especially during dry season. This might be due to the transformation of some pollutants accelerated by the dynamics of the water parameter with the changing season. The previous study on the dam by Mtavangu (2015) characterized the water in different times of the year and provided the cost effective and efficient - integrated constructed wetland and subsurface flow to treat turbid water, but did not analyze the transformation of pollutant in the dam with the changing season. The study did not analyse the diversity of harmful microbial species which could be the cause for some cattle death and sour taste of water. This study intended to assess the water quality and the transformation of the selected pollutants as well as the selected microbial organisms' variation with the changing seasons.

1.3 Objectives

1.3.1 General Objective

To assess seasonal dynamics of water quality parameters and transformation of selected pollutants in Nadosoito dam

1.3.2 Specific Objectives

(i) To examine the seasonal dynamics of selected water quality parameters in the Nadosoito dam

(ii) To examine the seasonal diversity of selected microorganisms (Cyanobacteria, FC) and transformational products of selected pollutants in the Nadosoito dam

1.4 Research Questions

(i) What are the seasonal dynamics of selected water quality parameters in the Nadosoito Dam?

(ii) What are the seasonal transformational products of the selected pollutant and microbial diversity in the Nadosoito dam?

1.5 Significance of the Study

Nadosoito Dam is the major source of water in Nadosoito and provides water for domestic and livestock throughout the year. Over 6000 inhabitants of Arkatani and surrounding villages depend on the dam for domestic supplies and watering animals (over 10 000 cattle, goats, sheep and donkeys), making it very important (Mtavangu, 2015). However the dam water varies in quality (which influence among others things, taste and odour) and quantity in different seasons of the year.This poses some adverse impacts to people and livestock (Kurunju, M. Personal communication, 2016). The data obtained from this research provides useful scientific information that give necessary information to guide the design and operation of the integrated IPS and other treatment systems to be installed at Nadosoito dam and other areas with similar properties. The study as well provide necessary recommendations to protect the water resource thereby protecting the health of human from water borne diseases and protecting the livestock as well.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Pastoralism, which is the main source of livelihood to about 120 million pastoralists worldwide, is practiced in the dry lands that are characterized by low rainfall and frequent droughts. However, frequent droughts have threatened this important sector which offers a viable production system in the vast dry lands of Kenya (Huho *et al*., 2011). In Tanzania, it is estimated that the pastoral economy is the basis of livelihood of 10% of the population. These groups are the backbone of Tanzania's livestock sector, owning approximately 99% of the livestock, while the big ranches and dairy farms own a mere 1% (Odhiambo, 2006). Arkatani being in the semi-arid area is experiencing drought and thus, scarcity of water for watering livestock and for domestic uses. Long term rainfall trend analysis (1984 to 2000) in the area classified rainfall in the range of minimum of <500 mm, moderate (500–600 mm), and highest of >600 mm (Msoffe *et al*., 2011). There are no perennial rivers and therefore the Nadosoito dam is the main source of water to cater for livestock and domestic use throughout the year. Despite the water's characteristic turbidity, the dam is shared by humans, livestock and wild animals, making it a potential source of zoonotic diseases. This also has the potential to add nutrients and organic matter when the animals drink from the dam. The study done by Mtavangu (2015) showed that, anthropogenic activities such as animal grazing, agricultural activities and natural sources such as land runoff were the main source of pollution for dam water source.

2.2. Seasonal Variation of Water Quality

Some physico-chemical parameters such as temperature and dissolved oxygen play vital roles in the rate of chemical reaction and nature of biological activities; they govern the assimilative capacity of the aquatic system (EPA, 1976; Forstner and Wittman, 1979). The results of the study done by Vaishali and Punita (2013) indicated the deteriorating water quality with significant seasonal changes e.g. the enhanced level of total dissolved solids (TDS), ammonia -N, BOD and decreased in pH, dissolved oxygen (DO) and Turbidity during winter season. The study on the dam by Mtavangu (2015) pointed out high pH and temperature during dry season but did not investigate their impact in the transformation of pollutants (e.g. nitrate and phosphorus) in water. Study by Untereiner (2015) indicated that dissolved oxygen is a function of temperature and presence of other aquatic organisms; colder waters tend to hold nutrients and gases better. Thus, climatic variables will affect whether anaerobic or aerobic nitrogen transformations take place. Gao *et al*. (2012) showed that, elevated pH promoted desorption of sedimentary inorganic phosphorus and facilitated conversion of ammonium (NH_4^+) to ammonia (NH_3). The same study also confirmed that progressive penetration of high pH from the overlying water into sediment promoted the mobility of soluble reactive phosphorus (SRP) and the release of total ammonium (NH_4^+) and ammonia (NH_3) into the water (Gao *et al*., 2012). When pH is above a critical threshold (9–9.2), inorganic phosphorus desorbs from iron oxides at mineral surfaces. It is clear that the critical threshold has something to do with the surface charge of iron oxides in combination with the speciation of P/PO_4 in this pH range (Andersen, 1975; Eckert *et al*., 1997). Increased water temperatures as well lead to desorption of phosphorus from sediment and increase its potential availability in water (Mayer and Gloss, 1980). This study intended to investigate these variations of physico-chemical properties of dam water and the impacts it has on the transformation of nitrogenous compounds, phosphorus and iron in varying season. Since the dam is the major source of water in the area, people therefore use the water despite of the water quality deterioration with season due limited alternatives. In rural and peri-urban areas of Tanzania, the use of contaminated and unsafe drinking water from surface water sources like rivers, lakes, earthen dams, wells and open springs is not optional due to limited piped water supply (Mohamed *et al.*, 2016). This puts people around the dam on the health risk from using the same water and hence calls for the study to check for the water quality dynamics. Seasonal changes in surface water quality must be considered when establishing a water quality management program (Ouyang *et al*., 2006).

2.3 Transformation of Pollutant in Water due to Seasonal Changes

Temperature and pH play a greater role in chemical reaction which can also enhance the transformation of pollutants in water that in-turns deteriorate water quality with seasonal changes. The study by Pejman *et al*. (2009) showed that the natural parameters (temperature and discharge), the inorganic parameter (e.g. total solid) and the organic nutrients (e.g. nitrate) were the most significant parameters contributing to water quality variations for all seasons. A study done by Adefemi *et al*. (2007) in water quality reported that, physico-chemical parameters determined were higher in the dry season than in the wet season. At elevated pH levels, high sediment-water effluxes of soluble reactive phosphorus and total ammonium were associated with reduction of nitrification, denitrification and oxygen consumption rates (Gao *et al.*, 2012). Nitrification is a process of ammonium ions (NH_4^+) biochemical oxidation to nitrates (NO_3^-), mediated by chemoautotrophic bacteria of the genus *Nitrosomonas* in the first step represented by equation (i) and *Nitrobacter* second step represented by equation (ii). The whole process is represented by equation (iii)

$NH_4^+ \rightarrow NO_2^-$……………………………….(i)

$NO_2^- \rightarrow NO_3^-$ ……………………………….(ii)

$NH_4^+ \leftrightarrow NH_3 \leftrightarrow NO_2^- \leftrightarrow NO_3^-$………………(iii)

Nitrifying activity is determined by physico-chemical factors such as temperature and oxygen concentration. It has been shown that suspended particulate matter stimulates nitrification processes (Polak and Kentzer, 2004). Hao and Martinez (1998) stated that, at oxygen concentration of 0.2-0.6 mg/dm^3, the main nitrification products are nitrites and that, nitrifying activity increase also at the temperature above 30^{o}C. Therefore during dry period, at high BOD values, there could be competition for oxygen and autotrophs activity and thus limitation of nitrification could occur. The organic and inorganic particulate and soluble forms of phosphorus undergo continuous transformations in water. The dissolved phosphorus (usually as orthophosphate) is assimilated by phytoplankton and altered to organic phosphorus. A portion of the phosphorus in the sediments and organisms may be reintroduced to the water column depending on bioturbation, physic-chemical properties of water and chemical transformations by water chemistry. Recycling of phosphorus often stimulates blooms of phytoplankton (Hoyer and Jones, 1983). This study therefore investigated the physico-chemical and biological variation of water with seasons and relates it with the selected pollutant transformation.

2.4 Seasonal Changes in Microbial Species Composition

Previous studies indicated that, physico-chemical parameters vary with seasons (Adefemi *et al*., 2007) which in turn influence the composition and transformation of nitrate and phosphorus in water systems (Gao *et al*., 2012). On the other hand, reactive nitrogen, including reduced (e.g. ammonium) and oxidized (nitrate, nitrite) forms, play central roles in modulating and controlling (limiting) primary and secondary production and species composition in freshwater ecosystems. These include lakes, reservoirs, dams, streams, rivers, and wetlands (Goldman, 1981; Paerl, 1982; Elser *et al*., 1990, 2007; Wetzel, 2001). Phosphorus has been considered the primary limiting nutrient in freshwater ecosystems (Schindler, 1971; Schindler *et al*., 2008) cited by Sab (2011). The shift in nutrient loading (increasing N:P) has led to a resurgence of toxic cyanobacterial blooms dominated by the non-N_2 fixing genus *Microcystis,* an indicator of excessive N loading (North *et al*., 2007). In addition to the importance, total Nitrogen loads play role in determining water quality status and trends, the supply rates and ratios of various reactive nitrogen forms play an important role in structuring microalgal and macrophyte communities mediating freshwater primary production (Paerl, 1988; McCarthy *et al*., 2007, 2009). For example, the ratio of ammonium to oxidized N was related to the proportion of cyanobacteria composing the total phytoplankton community (McCarthy *et al*., 2009). Some freshwater cyanobacteria are known to produce potent toxins while other cyanobacteria species (e.g. *Microcystis* sp) produce compounds causing unpleasant taste, odour and toxins (microcystins) (SCA, 2010). These have been associated with cases of aquatic life and wildlife poisoning and kills including some cases of human illnesses/deaths and water odour around the world (Mbukwa *et al*., 2013). Cases of illness and animal diarhoea in the Nadosoito dam are more pronounced during the peak of dry season and on the onset of rainfall which could as well be associated by the formation of cyanotoxins. The study therefore assessed transformation of pollutant in the dam and investigated their association with some harmful microbial species.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site Description

Nadosoito Dam is at Arkatani Village, Sepeko ward, Monduli district, Arusha, Tanzania (Fig. 1), with geographical coordinates, 03^o 18' S and 36^o 27' E. The name Nadosoito is a local Maasai word meaning "red stones", indicating the characteristic reddish stones/ rocks common around the dam area. Two small seasonal streams deliver water into the dam with it during the wet season. The dam receives water during the wet seasons only through those seasonal streams collecting water upstream of the dam and surface runoff from adjacent areas. When the dam is full it overflows through a spill way located on the lower side of the dam, here by referred as the Outlet (Fig. 1). After the rains, no inflow or outflow in the dry season, this water collected is stored to be used during the dry season.

A census in 2012 by the United Republic of Tanzania (URT) Bureau of Statistics recorded 158 929 people in Monduli district, of which, Sepeko ward recorded 16 720 people (URT, 2012). The population (majority Maasai) comprises mainly agro-pastoralists. They were previously purely pastoralist but agriculture is practiced nowadays as a strategy to cope with population increase and effects of climate change on their livestock. Sepeko is largely grassy low land with scattered shrubs, used for grazing.

Being a nomadic tribe, Maasai constantly move their herds searching for better grazing and water sources. Some, especially women and children stay at home and move only during severe droughts that lead to loss of water and grass. Most of the beans and maize farms which are only rain-fed, are located in the lower part on the south-west side of the dam. There are hills north of the dam and residential areas scattered around the dam.

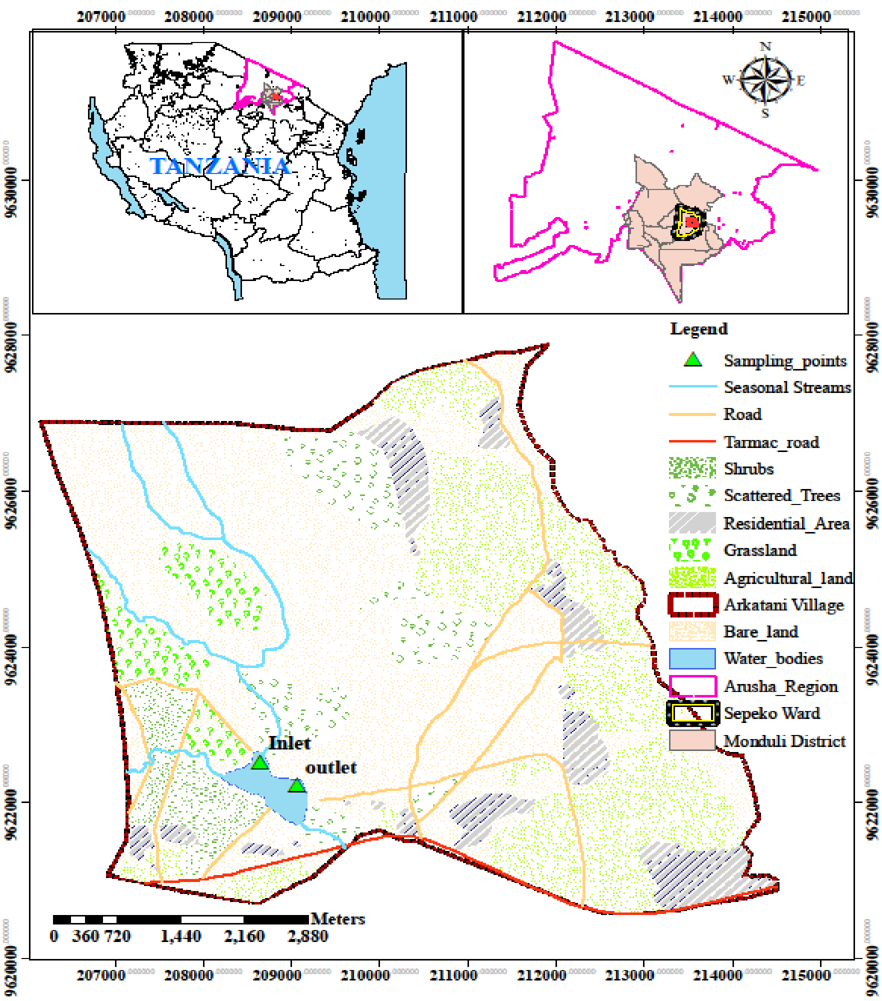


Figure 1: Map Showing the Location of Nadosoito Dam

The area is frequently drought stricken and people depend on the dam as the major water source. Average annual rainfall is 650 mm and the range in the long term rainfall trend analysis (1984 and 2000) extends from <500 to >600 mm (Msoffe *et al*., 2011). The dam water is characteristically turbid with very fine clayey particles, which settle slowly. An inclined plate settler (IPS) combined with a constructed wetland project is being installed by Nelson Mandela African Institution of Science and Technology (NM-AIST) to treat turbid water for domestic consumption. The figure below (Fig. 2) shows the rainfall distribution pattern of Monduli.

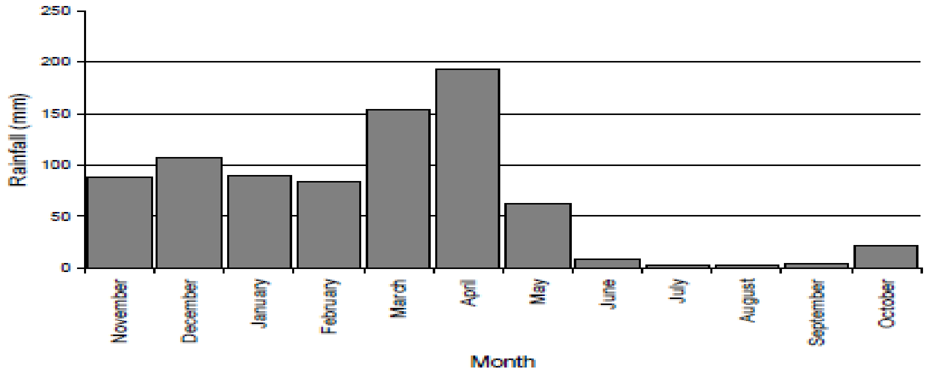


Figure 2: Monthly rainfall pattern in Monduli district (Source: Kshatriya *et al.*, 2007)

3.2 Site Selection Criteria

The site was selected considering the location of the Integrated Settling tank and IPS project by NM-AIST. The dam was selected by the project due to its water being characteristically highly turbid and difficult to settle. The water is shared by livestock and human presenting the dam to potential for microbial and nutrient contamination. Water quality varies with varying season increasing the severity of the effects on human health and livestock population.

3.3 Data Collection

3.3.1 Water Sample Collection

Water samples from the dam were collected twice a month (at the beginning and in the middle of the month) from the two selected points in the dam; main water entry point (Inlet) and spill way (Outlet) (Fig. 1). The "Inlet" is here by representing the water main entry point sampling point where as the "Outlet" represents the main exit of the water from the dam and will therefore be referred to as such. A total number of thirty samples were collected. Samples were collected from around 1000 h to 1500 h in all sampling session. This was important in order to sample during the time high biomass of the cyanobacteria (Ahn *et al.*, 2008), and also to harmonise the effects of temperature on the physico-chemical parameters. Sampling of physico-chemical parameters and samples to check for transformational of pollutants, were done using 500 mL polyethylene sampling bottles. The bottles were washed and rinsed thoroughly with distilled water then re-rinsed three times with the dam water before the samples were collected. Glass bottles of 250 mL were used to collect microbial analysis samples; the bottles were washed and rinsed with distilled water and then sterilized by autoclaving at 121^{o}C for 2 hours. The glass bottles were well re-rinsed three times with dam water before collecting samples. The samples for physico-chemical parameters were acidified with conc. H_2SO_4 at pH ≤ 2 to preserve them (APHA, 2012). All the samples were stored in ice cool box at 4 ^oC before analysis.

3.3.2 Water Sample Analysis

Analysis was carried out as per standard methods for the examination of water and wastewater (APHA, 2012). Fourteen physico-chemical parameters including temperature, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), turbidity, nitrate, nitrite, ammonia, phosphate, chemical oxygen demand (COD) and iron were analyzed. Two parameters i.e. fecal coliforms (FC) and phycocyanin (PC) unique to cyanobacterial were analyzed to ascertain the microbiological diversity of the water.

Most of the physico-chemical parameters were analysed onsite; pH, temperature, DO, EC, and TDS using HANNA Multiparameter (HI 9829). Turbidity was determined using turbidometer (HI 93703) after dilution of the samples (100 times in most cases in wet season) since the water was too turbid for the equipment. Total suspended solid (TSS) was analyzed by a direct measurement method by a spectrophotometer as per manufacturer's instruction. Nitrogenous species (NO_2-N, NO_3-N) and phosphate were analyzed in the laboratory in NM-AIST by HACH DR 2800 spectrophotometer. Nitrate was analyzed by cadmium reduction method, nitrite was determined by Diazotization Method and ammonia by Nessler Method.

Phosphate was determined by PhosVer 3 with acid Persulfate Digestion Method. COD was determined by Reactor Digestion Method using HACH COD digester and Multiparameter photometer (HI 83099) as per manufacture's instruction and Standard methods for examination of water and waste water (APHA, 2012). Iron was determined by a FerroVer Method using FerroVerr Iron Reagent as described by the APHA (2012) guideline. Phycocyanin pigment unique to cyanobacteria was analysed in situ by using *Aqua*Fluor model 8000-01 (serial # 8032-47). World Health Organization (WHO) water quality guidelines (Ahn *et al*., 2008; Brient *et al*., 2008; McQuaid *et al*., 2011), were used to interpret the phycocyanin concentration on the basis that, a concentration of 30 µg/L is equivalent to the WHO alert level of 20 000 cyanobacterial cells/mL, and less than 30 µg/L means that the number of cyanobacterial cells/mL is below the alert level.

Faecal coliforms was analysed by membrane filtration method. Samples were filtered using sterilized 0.45 µm pore size and 47 mm diameter filter membranes. The filters were incubated in MFC–agar medium with rozolic acid at 44.5 ^{o}C for 24 hours and thereafter the formed blue colonies were counted and reported per 100 mL of analyte (CFU/100 mL) (APHA, 2012). The detailed methods of analysis are appended as Appendix 1.

3.3.4 Statistical Analysis

Statistical analysis was done using OriginPro 8 to analyse pollutant transformation and their seasonal correlation. The Pearson correlation was ran in order to establish the relationship.

3.3.5 Sampling Strategy

Water samples were collected during wet season (January through May) and dry season (August and September, 2017) to ascertain the dynamics of parameter in changing seasons as well as the transformation process. August and September are chosen to represent dry season because they are the driest months of the year, as well, January through May were chosen to represent the wet months. (Kshatriya *et al*., 2007) (Fig. 2).

CHAPTER FOUR

RESULTS AND DISCUSSION

The general trend was for most physical parameters (e.g. turbidity, TSS) to decline between the Inlet and Outlet. Some parameters, like turbidity, increased with increasing rainfall (due to the high influx of suspended materials) while others, e.g. EC and TDS, declined with rainfall as a result of dilution. Nutrient concentrations (e.g. nitrate) were higher in the wet than the dry season, while nitrite and phosphate concentrations were higher in the dry than the wet season.

4.1 Seasonal Dynamics of Selected Water Quality Parameters in the Nadosoito Dam

4.1.1 Electrical conductivity (EC)

Electrical conductivity varied greatly between the wet and dry seasons, with maxima of 1356 and 5802 µS/cm respectively in the wet and dry seasons. The maximum wet season value (1356 µS/cm) was very different from the other wet season results and was determined at the onset of rainfall (January, 2017). This arose because of the transfer into the dam of organic and inorganic materials that had accumulated in the catchment. Other EC results from the wet season were in the range 243 to 412 µS/cm. These lower values arise mainly because of dilution by rainwater. The highest EC value was read, in both seasons, at the Inlet sampling site. The wet season variation is due to rain water dilution – only light rain had fallen by the time of the first sampling in January. The dry season variation was caused by the high rates of evaporation, which reduced the volume of water and concentrated the dissolved solids. Electrical conductivity has a very strong, positive significant correlation with TDS at both sampling location indicating relationship of EC with dissolved ions. It also showed non-significant, negative negligible correlation with nitrate at both sampling locations. Standard deviation of 304.19 µS/cm and 316.71µS/cm, 2121.33 µS/cm and 2099.58 µS/cm was obtained at the Outlet and Inlet in wet and dry seasons respectively. Electrical conductivity is used only to give an indication of possible water quality problems relating to dissolved ions of harmful pollutants.

4.1.2 Total Dissolved Solids (TDS)

Total dissolved solids varied from 141 to 882 mg/L, and from 822 to 3855 mg/L, in the wet and dry seasons respectively. The wet season TDS maximum was found at Inlet. The maximum TDS – 3855 mg/L – was obtained at Inlet too at the final sampling (dry season), in September, 2017. There was evidence of erosion on the sides of the dam during the wet season, at that time, indicating that large amounts of sediment had been discharged into the water, leading to high TSS and TDS concentrations. Erosion is likely to increase the TDS in water because it enhances the supply and transport of potentially soluble ionic components from the catchment into the dam. Also the physical disturbance of sediments (for this case by animals drinking from the dam) release metals more rapidly than biological disturbance (bioturbation) (Atkinson *et al*., 2007). This explains why we had high TDS in all the season irrespective the pH observed. The major cause for the TSS increase however is the the surface runoff from the adjacent grazing area trampled by herds of cattle and goats, producing very fine dust and washed into the dam. This was quite evident during the sampling time.

Water with TDS concentrations below 1000 mg/L is usually acceptable for domestic use, although this may vary according to circumstances (WHO, 2003). The TDS concentration in the dam was consistently below 1000 mg/L throughout the wet season and so within the acceptable limit. All dry season samples, apart from the first (1 August, 2017), had concentrations exceeding 1000 mg-TDS/L (Fig. 3), which might explain the objectionable taste of the water then, at least in part (Appendix 2). Heavy rainfall diluted the dam water and the TDS concentration decreased in wet season, while evaporation caused the TDS to increase in the dry season (Fig. 3). The TDS in the two sampling locations differed only slightly explaining that the rate of metal dissolution did not differ much across the dam.

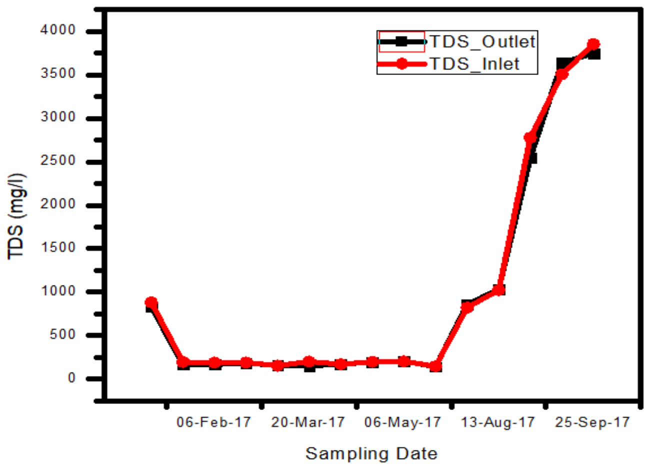


Figure 3: Total dissolved solids variation at the inlet and outlet sampling site from wet season to dry Season

4.1.3 Total Suspended Solids (TSS)

Total suspended solids concentrations ranged from 3820 to 46 600 mg/L and 1750 to 12 000 mg/L, in the wet and dry seasons respectively, at both sampling points. The general trend shows a decline from the wet to the dry season, the difference in two curves explains that the suspended material decrease from inlet to the outlet sampling - sedimentation process (Fig. 4). This parameter is a significant indicator of potential pollution because some pollutants and microorganisms can adhere to the suspended particles (Singh *et al.*, 2013).

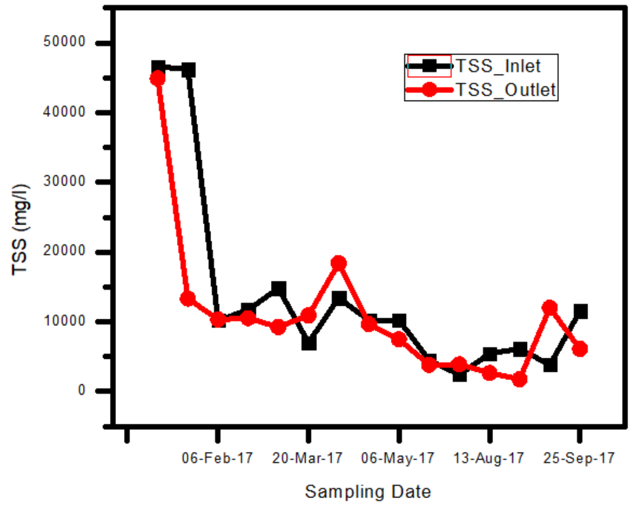


Figure 4: Total suspended solids variation at the Inlet and Outlet sampling site from wet season to dry season

4.1.4 Turbidity

Turbidity is another indicator of the amount of material suspended in water, and is a measure of the amount of light scattered or absorbed as it passes through the water column. It measures water clarity describing how far the light will go as it passes through water. Suspended silt and clay, organic matter, and plankton all contribute to turbidity. Turbidity at the dam ranged from 2920 to 53 300 NTU in wet season (Appendix 2), with mean values of 15 381 NTU at the Inlet and 11 737 NTU at Outlet (tables 1 and 2). In the dry season, the turbidity ranged from 204 to 4330 NTU, with means of 1265 NTU at Inlet and 1613 NTU at the Outlet. Such values indicate the potential presence of harmful contaminants.

Like TSS, turbidity was lower in the wet than the dry season, because settlement of solids is possible in the dry season. WHO recommend <5 NTU as an acceptable turbidity range for drinking water (WHO, 2006) while Tanzania Standards (TZS) for drinking water recommend a range of 5 to 25 NTU (TZS, 2003). For effective UV disinfection, the turbidity is recommended to be consistently less than 5 NTU—preferably below 1 NTU (WHO, 1997). The values obtained are far above the recommended range and the water requires treatment before consumption. Turbidity varied in line with TSS at both sampling locations (Fig. 5). In the context of the IPS it was noted that pre-treatment of such high turbidity water will require more settling/sedimentation time.

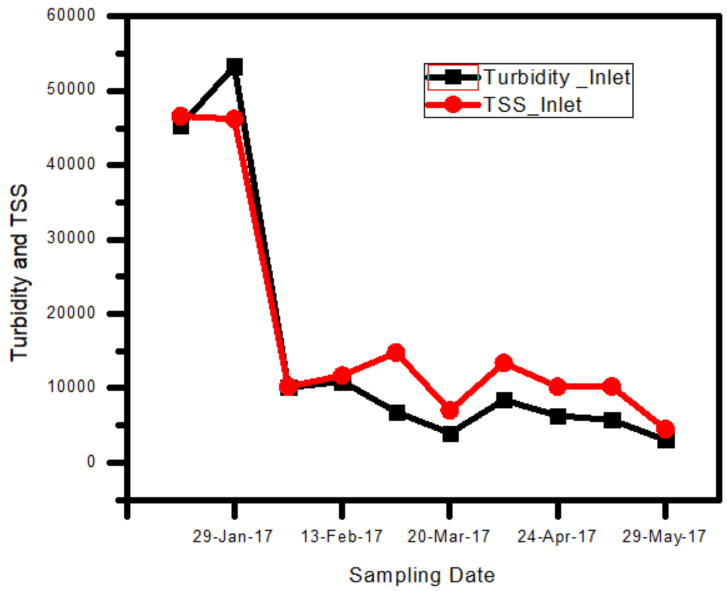


Figure 5: Turbidity and TSS variation trend for wet season (Inlet)

4.1.5 Dissolved Oxygen (DO)

Dissolved Oxygen (DO) concentrations ranged from 2.54 to 8.8 mg/L in the wet season and 1 to 8.05 mg/L in the dry season. The maximum concentration of DO was found at the Inlet in the wet season (January 2017) (Table 1) when the temperature was 25°C. The lowest DO, also at the Inlet, was observed at the end of dry season (September)(Table 4). DO is an important parameter in water quality assessment, and reflects the physical and biological processes prevailing in the water (Trivedy and Goel, 1984). Organic pollution, for instance, tends to remove much of the DO in aerobic biological decay, decreasing the amount in the water (Chhatwal, 2011). Other studies have related low DO concentrations to aesthetically displeasing colours, tastes and odours in water. DO depletion in water supplies can encourage microbial reduction of nitrate to nitrite and an increase in the concentration of ferrous iron in solution, with subsequent discoloration at the tap when the water is aerated (WHO, 2006). A similar relationship was established in this study, whereby, when the DO concentration was at its lowest the nitrite concentration was at its maximum (290 mg/L) – at the end of the dry season (September). No health-based guideline value is recommended for DO (WHO, 2006).

4.1.6 pH

The value of pH describes the acidity or alkalinity of water and represents the balance between hydrogen ions (H^+) and hydroxide ions (OH^-) in water. In this study, pH ranged from 7.01 to 9.81 across the seasons, with a wet season range of 7.01 to 8.8, and dry season range of 7.67 to 9.81 (Appendix 2). The highest wet season pH value (8.8) occurred in May (Table 3), and the highest in the dry season (9.81) in August, both at Outlet (Table 4).

The pH of water affects the solubility of many toxic and nutritive chemicals; hence, the availability of these substances to aquatic organisms is affected. As acidity increases, most metals become more water soluble and more toxic. Ammonia, however, becomes more toxic with only a slight increase in pH (Vaishali and Punita, 2013). In this study NH_3-H had a very low positive correlation with pH ($r = 0.293$, $p = 0.411$) during the wet season, and ($r = 0.003$, $p = 0.996$) in dry season. The pH of water may have an effect on the treatment of water and so should be considered as an important parameter in the treatment. It is therefore necessary to know the pH of water, because more alkaline water requires a longer contact time or a higher free residual chlorine level at the end of the contact time for adequate disinfection (0.4–0.5 mg/litre at pH 6–8, rising to 0.6 mg/L at pH 8–9; chlorination may be ineffective above pH 9 (WHO, 2006). The water was generally more alkaline in the dry season than the wet.

4.1.7 Temperature

Temperature is an important parameter as it affects the rate of chemical and biological reactions in water. Temperature also influences the ability of water to hold oxygen - as the temperature increases the ability of water to hold dissolved oxygen is decreased. This is well demonstrated by the Temperature and DO data at both location. Temperature also affects the rate of photosynthesis and other metabolic reaction by the organisms in water. It also has the impact in the level of ammonia gas in water. The temperature of the water in the dam ranged from 19.55 ^{0}C (1 August, 2017) to 33.41 ^{0}C (20 March, 2017) (Appendix 2), both measurements made at the Outlet. Persistence of microorganisms in water is affected by several factors, of which temperature is the most important. Decay is usually faster at higher temperatures and may be mediated by the lethal effects of ultraviolet (UV) radiation in sunlight acting near the water surface (WHO, 2006). A guideline for drinking water by WHO (2006) provides that, at the range of 25–50 °C of temperature, a wide range of microorganisms proliferate – most of the values read during the sampling sessions falls in this range.

4.1.8 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand is non-conventional pollutant that can be used to characterise concentration of organic pollutants and provide data on the existence of organic substances that can only be oxidised by aerobic biological processes (USEPA, 1993). Some of these organic substances can be harmful. The COD level at the two sampling locations ranged from <0.7 to 87 mg/L. Although this parameter is not considered as a direct risk, it should be noted that, most of the data obtained from the study were higher than the threshold value of 5 mg/L prescribed for water intended for consumption (WHO, 2006), probably expressing the presence of high concentrations of organic substances in the dam and potential for the health problems. It is a measure of the amount of oxygen required to oxidize dissolved organic and inorganic material, and is commonly used as an indirect measure of the concentration of organic compounds in water (Kumar *et al*., 2011). The minimum was obtained at both locations on 1 August, 2017, in the dry season, the maximum at Inlet in April, 2017 (Table 1). The highest COD level at Outlet was 29.1 mg/l, it occurred on 07 March, 2017 (Table 3). The maximum and minimum levels generally arose from the material loads brought into the dam by surface runoff and subsequent settling, respectively. This is due to the fact that, much material is brought into the dam by the surface runoff during the wet season while no material is brought into it during the dry season, since there is no river feeding into the dam. The general trend for COD to decrease from Inlet to the Outlet, and from the wet to the dry season is accounted for by several factors including; material sedimentation, possible removal of organic substrate that is coupled with the formation of the biomas and the consumption of dissolved oxygen (Orhon *et al.,* 2009). This makes COD useful indicator of organic pollution in surface water (Faith, 2006).

4.2 Seasonal Diversity of Microorganisms and Transformational Products of Selected Pollutants

4.2.1 Ammoniacal–nitrogen (NH_3-N)

The most important source of ammonia in the dam water is the ammonification of organic matter. Animal and human excreta contain large proportions of nitrogenous matter, so their presence and decomposition in water tends to increase ammonia concentrations. Ammonia's presence in waters provides chemical evidence of organic pollution (Trivedi and Goel, 1984). The concentration of ammonia (NH_3-N) ranged from 0.14 to 270 mg/L in the wet season and 2.2 to 27 mg/L in the dry. The concentration increased with increasing rainfall in the wet season at both sampling locations; with the highest value occurring at Inlet in April (Table 3). The maximum concentration at outlet sampling point was 213 mg/L, also in April (Table 1).

The increase recorded can be accounted for by and/or indicate the discharge of animal and human excreta from the catchment with the runoff, the depositing of animal excreta as they drink from the dam, and/or ammonium fertilizers in runoff from farms in the catchment. Standard deviation of 74.967 mg/L and 95.257 mg/L was obtained at inlet and outlet respectively in the wet season while the dry season values were 7.21 and 10.53 mg/L at inlet and outlet respectively. The high deviation in wet season was a result of very high ammonia value obtained in April 2017 sampling as compared to other sampling events. Big number of herds of animals and their excreta was observed in and around the dam during all the sampling times. Also signs of erosions and runoff of water was vivid in the area, signifying the washout of the soil together with the organic materials into the dam. Ammonia can compromise disinfection efficiency, resulting in nitrite formation in distribution systems, and also cause taste and odour problems (WHO, 2006). The threshold odour concentration of ammonia at alkaline pH is approximately 1.5 mg/L, and a taste threshold of 35 mg/L has been proposed for the ammonium cation. This helps further to explain why water in the dam has objectionable taste and odour problems at some periods of the year. Ammonia is not of direct relevance to health at these levels, and no health-based guideline value has been proposed (WHO, 2006). The TZS however has set 0.5mg/L of Ammonia as the maximum permissible concentration for drinking water. Looking at the data, all the values in both the sampling point has values exceeding the maximum permissible concentration. The water in the dam therefore require treatment to reduce the ammonia to the required TZS value before it can be used for drinking.

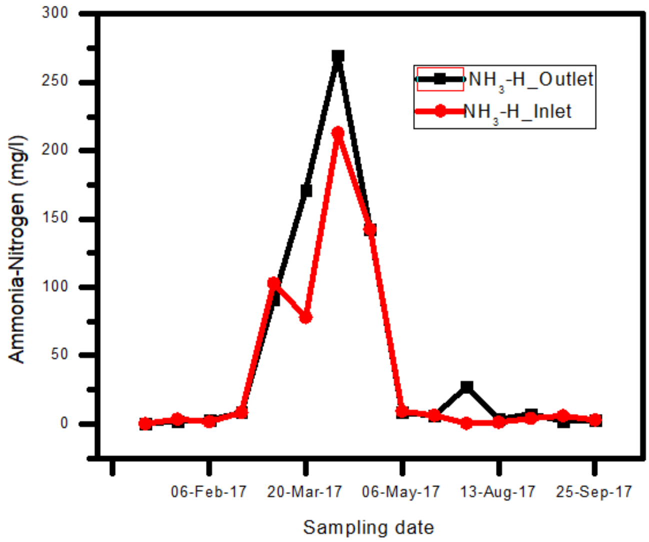


Figure 6: Ammoniacal-nitrogen variation in the wet season

4.2.2 Nitrate (NO_3-N)

Nitrate (NO_3-N) was generally higher at Inlet than Outlet in samples taken in the wet season. The concentration was below 10 mg-N/L (the WHO guideline level for drinking water) in only two samples (both taken in January) from Outlet. In the dry season, all determinations of NO_3-N, except one (in August), at inlet – 4 mg/L – exceeded the guideline value. The highest level reported was 1715 mg-N/L read at WWE in March. NO_3-N was higher at Inlet than outlet for all but four sampling sessions – the latter were 13 February, 20 March, and 6 and 29 May, 2017, all in the wet season. The difference in the two locations can explain the reduction of nitrate as water move down to the Outlet. On the other hand, this can be explained by the increase of the concentration of NH_3-N as the water moves from the water main entry point (Inlet) to Outlet, in all the session, with exception of one sampling session (29 January, 2017).

The maximum NO_3-N concentration in the dry season was 512 mg-N/L, in the August sample from Outlet. There was significant variation in NO_3-N concentrations between the sampling sessions, with standard deviations of 207 and 135 mg-N/L for Outlet and Inlet respectively.World Health Organization has set a maximum contaminant level of 10mg/L for nitrate as NO_3-N for drinking water. NO_3-N levels above 10 mg/L may present a serious health concern for infants and pregnant or nursing women; it may give rise to methaemoglobinaemia to infants (WHO, 2006). The values indicate that the mentioned are exposed almost throughout the year since they use the dam water untreated.

4.2.3 Nitrite

Nitrite is more toxic than nitrate. The WHO provisional long-term exposure guideline for NO_2-N is 0.2 mg-N/L (WHO, 2006). As for nitrate, the presence of nitrite in water is associated with methaemoglobinaemia, especially in bottle-fed infants (WHO, 2006). With a single exception – 03 April, at Inlet –all wet season samples at Inlet reported NO_2-N below the WHO guideline. In the dry season all samples from both locations reported NO_2-N concentrations significantly above the WHO guideline. The highest concentration – 290 mg-N/L – was obtained at outlet on 25 September and the minimum – 0.209 mg-N/L– on 1 August. Clearly, the dam water will require effective treatment to remove nitrite to the level recommended for drinking – especially in the dry season. Hao and Martinez (1998) stated that, in nitrification process at oxygen concentration of 0.2-0.6 mg/dm^3, the main nitrification products are nitrites. This can be related to the high nitrite level in dry season where the analyzed level of DO was lower compared to the level in wet season. Nitrite had a negative correlation with DO (r=-0.417, p=0.485) at the Outlet indicating the denitrification, while it has a very strong positive correlation at the inlet ($r = 0.998$, $p < 0.01$).

4.2.4 Phosphate

Phosphate (PO_4^{3-}) concentrations varied in the wet season from 0.06 to 10 mg/L at the two sampling points. PO_4^{3-}concentrations were generally fairly similar at Inlet and Outlet (tables 1 and 2). The higher concentrations, 2 to 10 mg-P/L were recorded between March and May when there were long periods of rainfall. Phosphate concentrations were higher in the dry than the wet season. The minimum and maximum dry season concentrations were 0.31 and 15.2 mg-P/L respectively (tables 2 and 4) – the latter from outlet on 25 September. The high phosphate concentration might be related to the elevated level of pH in the dry season (Gao *et al*., 2012), as this promotes desorption of sedimentary inorganic phosphorus. This matches with the data at outlet in which phosphate had a strong positive correlation with pH at Outlet (pH-Phosphate ($r = 0.683$, p=0.204) but was contrary to the values at the Inlet that showed a weak negative correlation ($r = -0.297$, $p = 0.405$).

4.2.5 Iron

The Iron concentrations ranged from 13.0 to 1380 mg/L. The highest value was reported from inlet in the first January sampling. Iron concentrations differed significantly between the wet and dry seasons, with the higher levels occurring in the wet season.

As all the water in Nadosoito dam is derived from surface runoff, the iron concentration in its water is likely to increase during rainfall. This is due to the possible release of soluble iron to water from natural deposits in soil, leaching from underlying rocks and stones on the catchment. Iron is involved in phosphorus dynamics in fresh water, Fe (III) oxides and hydroxides readily adsorb and precipitate phosphate. This could explain the differences between phosphate concentrations in the wet and dry seasons. In aerobic conditions, interactions between colloidal organic material and iron decrease the extent of phosphate adsorption onto Fe-organic complexes and increase the availability of P to phytoplankton (Koenings and Hooper, 1976) and cyanobacteria (PC concentration). This matches with the data obtained which showed positive negligible correlation between Iron and PC in both location during the wet season. Whenever human activities, e.g. pastoralism and cultivation, disturb the balance of soils rich in iron, the inflow of iron into the water system is likely to be enhanced (Heikinnen, 1990). This is because the loose soil particles are prone to erosion by the surface runoff, and subsequent washout into the dam than the intact soil that is not disturbed.

4.2.6 Phycocyanin Pigment (PC)

In the wet season, the phycocyanin concentration varied from 38.1 to 495 µg/L. It was highest in January at the Inlet and lowest in April at the Outlet. The mean PC concentrations recorded in the dry season were 94.8 and 104.0 µg/L at Inlet and Outlet, respectively; relatively much closer than in the wet season. The most likely time for a cyanobacteria bloom is after inflows delivering significant quantities of nutrients to the reservoir. The minimum concentration in the dry season was 19.9 and the maximum 175.7 µg/L. Since a phycocyanin concentration of 30 µg/L is interpreted as equivalent to WHO "alert level 1" of 20 000 cyanobacterial cells/mL (Brient *et al*., 2008), this implies that the PC concentration in all but one sampling session in both seasons exceeded the WHO alert level. (In one case in the dry season the PC concentration was reported as 19.85 µg/L.) Without essential nutrients, principally nitrate and phosphate, algae will usually not reach bloom proportions and PC concentrations are expected to be low. Excessive nutrient input from land-based sources is a major cyanobacterial bloom promoting factor (WHO, 2003).

Broadly, the phosphorus and nitrogen loads determine the rate and magnitude of cyanobacterial growth (PC concentration), which means that higher loads imply greater potential algal growth (Wetzel, 2001). This was shown in this study when high PC concentrations in the wet season coincided with high nitrate concentrations. This can be revealed by the correlation analysis which showed negligible positive correlation with Nitrate-Nitrogen at Outlet (r = 0.222, p = 0.537). The phosphate trend opposed that of the PC concentration, being higher in the dry season than the wet. Medium- to long-term management measures for cyanobacterial control include; Identification of nutrient sources (phosphorus and nitrogen) and significant reduction of nutrient input, to reduce the proliferation of both cyanobacteria and other potentially harmful algae (WHO, 2003). Reports from the USA have recorded allergic reactions from recreational exposure, and the cyanobacteria pigment phycocyanin has been shown to be responsible in one case (Cohen and Reif, 1953). Carmichael (1994) compiled case studies on nausea, vomiting, diarrhoea, and fever, eye, ear and throat infections after exposure to mass developments of cyanobacteria. Cases of deaths among cattle, sheep, dogs, horses and pigs after drinking water containing cyanobacteria were reported by Francis (1878).

4.2.7 Fecal Coliforms

Faecal coliform concentrations generally declined from wet to dry season (Fig. 7), with mean values of 3213 and 2029 CFU/100 mL at Inlet and Outlet, respectively, during the wet season. The maximum value recorded in the wet season was 8810 CFU/100 mL at utlet, while the minimum was 760 CFU/100 mL also from the same location (Table 1). The maximum value was recorded at the beginning of the wet season in January, and arose because of the additional contamination from the catchment brought in by the surface runoff associated with rainfall. The minimum dry season value of 30 CFU/100 mL was obtained at inlet in September, on the last sampling run of the season, while the maximum value in dry season – 710.5 CFU/100 mL – was obtained at outlet. All values from all sampling events exceeded the WHO guidelines and the TZS value of zero CFU/100 mL (TZS, 2003; WHO, 2006). The contamination is related to the transport – by runoff, etc. – of animal and human faecal matter to the dam, and direct defecation by livestock as they drink from the dam.

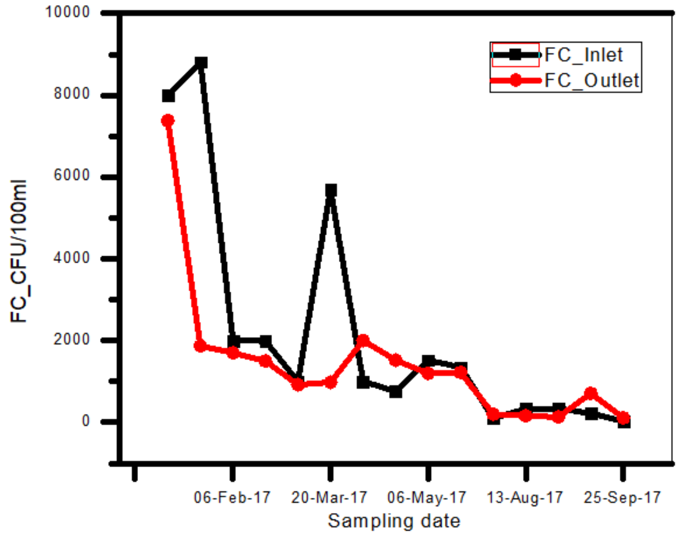


Figure 7: FC concentration variation at the inlet and outlet sampling site from wet season to dry season

4.3 Statistical analysis

4.3.1 Correlation analysis

In order to describe the relationship between physico-chemical parameters, and bacterial parameters of the dam water, Pearson correlation was used. The variables were classified as per Guildford's rule of thumb for interpreting correlation coefficient (Guilford, 1973) cited by Kura *et al*. (2013). The interpretation is based on correlation coefficient value (*r*), where 0.0 to 0.29 show negligible or little correlation, 0.3 to 0.49 low correlation, 0.5 to 0.69 moderate or marked correlation, 0.7 to 0.89 high correlations and 0.9 to 1.00 very high correlations.

During the wet season very high positive correlation existed between EC-TDS ($r = 0.998$, $p < 0.01$), at Outlet and $r = 0.998$ and $p < 0.01$) for Inlet. Very high positive correlation also existed between EC and turbidity and TSS at the Outlet ($r = 0.944$, p< 0.01), ($r = 0.938$, $p < 0.01$) respectively, and for the inlet the correlation between EC and turbidity and TSS was moderate ($r = 0.603$, $p = 0.064$), ($r = 0.682$, $p = 0.030$). Nitrate had negative negligible correlation with EC, TDS, turbidity and TSS in both the location with values ($r = -0.222$, p= 0.539), ($r = -0.230$, $p = 0.030$), ($r = -0.267$, $p = 0.456$), ($r = -0.160$, $p = 0.660$), respectively at the outlet and ($r = -0.172$, $p = 0.634$), ($r = -0.198$, $p = 0.583$), ($r = -0.116$, $p = 0.750$) at the inlet (appendices 3.1 and 2). Total suspended solids and turbidity, TDS and EC had a very strong positive correlation of in both the location. At the inlet, DO had low negative correlation with Temperature of $r = -0.432$, $p = 0.212$ this means that, cold water hold oxygen better than warmer water which is supported by the study done by Gao *et al*., in (2012), same trend was read at the Inlet (r = -0.247, p = 0.689. Nitrite-N at outlet had a high negative correlation (r = -0.715, p = 0.285) with DO and a low negative correlation (r = -0.445, p = 0.555) with temperature. It had a positive low correlation (r = 0.317, p = 0.373) with pH. This shows that the transformation of nitrate to nitrite is influenced by climatic variables. Phycocyanin pigment has a low positive correlation (r = 0.30541, p = 0.39081) with phosphate at Outlet and high positive correlation at Inlet (r = 0.726, p = 0.0173). It had a negligible positive correlation with Nitrate-Nitrogen (r = 0.222, p = 0.537) at Outlet and a negative low correlation (r = -0.379, p = 0.281) at inlet (appendices 3.1 and 3.2).

Phycocyanin also had a positive low correlation with pH (r=0.307, p=0.389) and a positive negligible correlation with Iron (r = 0.181, p = 0.617) at the Outlet; At Inlet, PC-pH had negative low correlation of r = -0.453, p = 0.188 and PC-Iron correlation was r = 0.112, p = 0.756. At outlet, FC had a very high positive correlation (r = 0.977, p <0.01) with COD and negative negligible correlation with DO and temperature of the values (r = -0.069, p = 0.849) and (r =-0.296, p = 0.705) respectively; whereby at Inlet PC had low positive correlation (r = 0.118, p = 0.746) with COD and a negative low correlation (r = -0.316, p =0.605) with DO and a negligible negative correlation (r =-0.230, p = 0.521 with temperature.

Faecal coliforms had a negative negligible correlation with turbidity (r =-0.278, p = 0.438), Positive negligible correlation with nitrate (r = 0.164, p = 0.651) and very high positive correlation with phosphate and nitrite of (r = 0.982, p <0.01) and (r = 0.979, p < 0.01) respectively at outlet, different trend was read at the Inlet where by FC-Nitrate was r =-0.277, p = 0.439 and FC-phosphate was r = 0.433, p = 0.727.

During the dry season; at outlet, PC-FC had a very strong positive correlation (r = 1, p <0.01), PC-Iron (r =0.397, p = 0.509), PC-COD was (r = 0.650, p=0.235), PC-Phosphate (r = 0.675, p = 0.211), PC-nitrite (r = 0.344, p=0.571), PC-NO_3-N (r = -0.503, p = 0.388), PC-NH_3-N (r = -0.194, p = 0.754), PC-DO (r = -0.644, p = 0.241), PC-pH (r = 0.951, p = 0.013), PC-Temp (r = 0.717, p = 0.173), FC-Turbidity (r =-0.794, p = 0.109), FC-Temp (r =0.718, p =0.172), PC-Temp (r =0.717, p = 0.173) (Appendix 3.2) same response of temperature for both PC and FC demonstrating that the proliferation of microorganisms is enhanced by the increase in temperature. Dissolved oxygen-COD was (r = -0.316, =0.605) symbolizing the consumption of oxygen by the degradation of organic materials by microorganisms, DO-Phosphate (r = -0.997, p <0.01), Nitrite – DO (r =-0.417, p =0.485) indicating the transformation of nitrate to nitrate (denitrification) as a results of low DO concentration, DO-Nitrate (r = -0.316, p = 0.604), DO-NH_3 (r = 0.394, p = 0.512), DO-pH (r = -0.643, p = 0.242), pH –FC (r = 0.95069, p = 0.013), pH-COD (r = 0.389, p = 0.517), pH-Phosphate correlation was in the level of (r = 0.683, p = 0.204) demonstrating the transformation of phosphate by the desorption of phosphorus from the sediment into water with the increase in pH – thus increasing the potential availability of phosphate in the water (Hao and Martinez 1998; Polak and Kentzer, 2004). Nitrite-pH (r = 0.569, p =0.317), pH-nitrate (r = -0.492, p = 0.400), pH-DO (r = -0.643, p = 0.242), pH-Temp (r = 0.663, p = 0.222), pH-Turbidity (r = -0.845, p =0.071), Temp – Phosphate (r = 0.517, p = 0.373), Temp-Nitrite (r = -0.144, p = 0.817), Temp-NH_3 (r =-0.620, p = 0.265), Temp-Nitrate (r =-0.246, p = 0.690), Temp-DO (r =-0.460, p = 0.43589) – this matches with the results from the study by Untereiner (2015) that, colder water holds DO better than warmer water.

At Outlet the trends were as follows: Phycocyanin-FC was different from trend at the Outlet which was very strong positive correlation (r = 1, $p < 0.01$). Here the correlation was (r = 0.596, p = 0.069), PC-Iron (r = 0.113, p = 0.756), PC-COD (r = -0.645, p = 0.044), PC-Phosphate (r = 0.727, p = 0.017) – the increase of phosphate in water favored the growth of cyanobacteria in water (Hoyer and Jones, 1983). PC-NO_3-N (r =0.379, p = 0.281), PC-NH_3-N (r = -0.230, p = 0.524), PC-DO (r = -0.449, p = 0.448), PC-pH is different from the one at Outlet which had a positive correlation, here the values were (r = -0.453, p = 0.188), PC-Temp (r = -0.449, p = 0.193), FC-Turbidity (r = -0.794, p = 0.109), FC-Temp had a high positive correlation at the outlet (supporting the proliferation with increase in temperature) contrary to the Inlet which was (r = -0.23091, p = 0.52096), FC-DO (r = -0.31569, p = 0.605), PC-Temp (r = -0.449, p = 0.193). DO-COD (r = 0.277, p = 0.652), DO-Phosphate (r = -0.594, p = 0.29101), DO-Nitrate (r = 0.998, p <0.01) – high concentration of DO promoted the nitrification process by the microorganisms, DO-NH_3 (r = 0.992, p <0.01), DO-pH (r = 0.932, p = 0.021), DO-Temp (r = -0.247, p = 0.689) – as the value in the Outlet, this also matches with other studies that colder water holds DO better. pH –FC (r = -0.276, p = 0.440), pH-COD (r = 0.263, p = 0.463), pH-Phosphate (r = -0.297, p = 0.405), pH-nitrate (r = 0.293, p = 0.411), pH-DO at outlet it has moderate negative correlation and at the Inlet the values were (r = 0.900, p <0.01), pH-Temp (r = 0.932, p = 0.021), pH-Turbidity r =0.340, p = 0.337), Temp – Phosphate (r = -0.126, p = 0.729), Temp-NH_3 (r = 0.1472, p = 0.685), Temp-Nitrate (r = 0.304, p = 0.392), COD-EC was different from the value at the outlet which was high strong positive correlation, the value here was (r = -0.515, p = 0.128). (Appendix 3.2)

4.3.2 Maximum and Minimum Values for the parameters

Table 1: Maximum and Minimum values – Inlet Wet Season (Jan to May)

Parameter	Minimum	Maximum
Temp (^{0}C)	24	32.28
pH	7.01	8.68
DO_mg/l	2.67	8.8
EC_µS/cm	256	1356
TDS _mg/l	146	882
Turb _NTU	3030	53300
TSS_mg/l	4480	46600
NO_3-N (mg/l)	0.6	1715
$N0_2$-N_mg/l	<LoD	11.2
NH_3-N_mg/l	0.14	213
$PO_4^{3-(}$mg/)l	0.08	8
COD (mg/l)	5.54	87
Iron(T) mg/l	25.5	1380
FC_CFU/100ml	760	8810
PC(µg/l)	60.61	495

N=10

Table 2: Maximum and Minimum values –Inlet Dry Season (August to September)

Parameter	Minimum	Maximum
Temp (^{0}C)	23.25	26.2
pH	7.67	8.96
DO_mg/l	2.5	7.76
EC_µS/cm	1361	5802
TDS _mg/l	822	3855
Turb _NTU	204	2080
TSS_mg/l	2400	11525
NO_3-N (mg/l)	4	292
$N0_2$-N_mg/l	2.4	19.25
NH_3-N_mg/l	0.52	5.9
PO_4^{3-}(mg/)l	0.31	3.81
COD (mg/l)	<LoD	2
Iron(T) mg/l	13	17
FC_CFU/100ml	30	340.38
PC(µg/l)	61.51	160.3

N=10

Table 3: Maximum and Minimum values – Outlet Wet Season (Jan to May)

Parameter	Minimum	Maximum

Temp (^{0}C)	21	33.41
pH	7.53	8.8
DO_mg/l	2.54	7.8
EC_µS/cm	243	1274
TDS _mg/l	141	830
Turb _NTU	2920	44700
TSS_mg/l	3820	44900
NO_3-N (mg/l)	3.6	351
$N0_2$-N_mg/l	<LoD	2.8
NH_3-N_mg/l	0.16	270
$PO_4^{3-(}$mg/)l	0.06	10
COD (mg/l)	2.02	29.1
Iron(T) mg/l	15.5	1300
FC_CFU/100ml	920	7380
PC(µg/l)	38.1	490

N=5

Table 4: Maximum and Minimum values – Outlet Dry Season (August to September)

Parameter	Minimum	Maximum
Temp (^{0}C)	19.55	26.86
pH	7.67	9.81
DO_mg/l	1	8.05
EC_µS/cm	1322	5766
TDS _mg/l	856	3748
Turb _NTU	670	4330
TSS_mg/l	1750	12000
NO_3-N (mg/l)	30	512
$N0_2$-N_mg/l	0.209	290
NH_3-N_mg/l	2.2	27
PO_4^{3-}(mg/)l	0.61	15.2
COD (mg/l)	<LoD	2.7
Iron(T) mg/l	18	26
FC_CFU/100ml	110	710.5
PC (µg/l)	19.9	175.7

N=5

CHAPTER FIVE

CONCLUSION AND RECOMENDATIONS

The results obtained indicate high levels of turbidity (204 to 53 300 NTU) and high NO_3-N concentrations (0.6 to 1715 mg-N/L), both of which require proper treatment to bring them to the TZS prescribed a range (5 to 25 NTU and 10 to 75 mg-$N0_3^-$/L respectively).

The concentration of faecal coliform (FC) was highest in the wet season (8810 CFU/100 mL) with a minimum value of 30 CFU/100 mL obtained in the dry season, both at Inlet. The highest and minimum FC concentrations at Outlet were 7380 and 110 CFU/100 mL respectively. All values in both seasons were above the TZS and WHO recommended values for drinking water (0 CFU/100mL). The maximum value arose from the very high contaminant loading in the runoff into the dam during the wet season.

The observed phycocyanin concentration (19.9 to 495 µg/L) is a useful surrogate for the concentration of cyanobacteria present. The WHO guideline alert level for phycocyanin is 30µg/L. The rather high concentrations of cyanobacteria, and hence phycocyanin, can probably be related to the incidence of diarrhoea among livestock and people, as well as livestock mortalities reported in the area. As explained by Brookes *et al.* (2002), the growth of cyanobacteria cells is favored in water that is nutrient-rich, warm and slow flowing, Brookes *et al.*, (2002) cited by Qian (2012). The higher levels coincide with the wet season when there are significant runoff inflows that deliver large quantities of nutrients to the reservoir.

Nadosoito dam, like other earthen dams, has calm, nutrient-rich, warm and slow-flowing water, thus favouring the growth and proliferation of cyanobacteria. This is well depicted in the results. While there is little that can be done to control such proliferation in earthen dams, investigations into ways to reduce nutrient loading in the influent – e.g., runoff – could provide a solution that might reduce the associated human and livestock health impacts to a large extent.

Summing up the obtained data and looking on the trends, there is a variation on the major parameters with the significant changes on the seasons. Furthermore, the statistical analysis of the data revealed the transformation of nitrate and phosphate with significant changes in the physical parameters (e.g. the increase of phosphate as the results of desorption of phosphate associated with the increase in pH and temperature and the enhanced nitrification process with the increase in the DO concentration). Also the PC concentration and FC were found to be moderated by physical water parameters including temperature and pH.

Inclined Plate Settler system developed and tested at NM-AIST laboratories have been shown to be effective in removing turbidity from the dam water to acceptable TBS levels (<25 NTU) and is ready to be tested in the field. As it is also necessary to reduce the nutrient and organic matter concentrations, the trial system is also coupled to a constructed wetland. The study by Paschal *et al*. (2017) indicated the efficiency of the constructed wetland to remove nutrient such as phosphate up to 60.4%, 62.0% of COD and 76.7% of TSS.

The results obtained from this study help to provide the necessary guidelines for the design and operation of the IPS-constructed wetland system. The outcome will be to increase access to safe drinking water, thereby reducing the human health impacts associated with direct use of the dam water and reducing local medical costs.

As most of the parameters determined reported higher values at the Inlet sampling point, it is recommended that water for treatment by the IPS-constructed wetland system is drawn from the vicinity of the Inlet sampling point.

REFERENCES

Adefemi, O. S., Asaolu, S. S. and Olaofe, O. (2007). Assessment of the physico-chemical status of water samples from major dams in Ekiti State, Nigeria. *Pakistan Journal of Nutrition*. **6**(6), 657-659.

Ahn, C. Y., Joung, S. H., Park, C. S., Kim, H. S., Yoon, B. D. and Oh, H. M. (2008). Comparison of sampling and analytical methods for monitoring of cyanobacteria-dominated surface waters. *Hydrobiologia*. ***596***(1), 413-421.

Andersen, J. M. (1975). Influence of pH on release of phosphorus from lake sediments. *Archiv fur Hydrobiologie*. **76**(4), 411-419.

APHA(Eds)(2012). *Standard Methods for the Examination of Water and Wastewater*, American Public Health Association (APHA)/American Water Works Association (AWWA)/Water Environment Federation (WEF), Washington DC, USA.

Atkinson, C. A., Jolley, D. F. and Simpson, S. L. (2007). Effect of overlying water pH, dissolved oxygen, salinity and sediment disturbances on metal release and sequestration from metal contaminated marine sediments. *Chemosphere*. ***69***(9), 1428-1437.

Brient, L., Lengronne, M., Bertrand, E., Rolland, D., Sipel, A., Steinmann, D., Baudin, I., Legeas, M., Le Rouzic, B. and Bormans, M. (2008). A phycocyanin probe as a tool for monitoring cyanobacteria in freshwater bodies. *Journal of Environmental Monitoring*. **10**(2), 248-255.

Brookes, J., Baker, P. and Burch, M. (2002). Ecology and management of cyanobacteria in rivers and reservoirs. Cooperative Research Centre for Water Quality and Treatment. Adelaide, Australia. pp.33-42.

Bu, H., Tan, X., Li, S. and Zhang, Q. (2009). Water quality assessment of the Jinshui River (China) using multivariate statistical techniques. *Environmental Earth Sciences*. ***60***(8), pp 1631–1639.

Carmichael, W. W. (1994). The toxins of cyanobacteria. *Scientific American*. **270**(1), 78-86.

Chhatwal, R. J. (Eds)(2011). Environment Sciences - A Systematic Approach. UDH Publishers and Distributors(P) Ltd, Delhi, India. pp 104-105.

Cohen, S. G. and Reif, C. B. (1953). Cutaneous sensitization to blue-green algae. *Journal of Allergy*. **24**(5), 452-457.

Eckert, W., Nishri, A. and Parparova, R. (1997). Factors regulating the flux of phosphate at the sediment-water interface of a subtropical calcareous lake: A simulation study with intact sediment cores. *Water, Air, and Soil Pollution*. **99**(1-4), 401-409.

Elser, J. J., Marzolf, E. R. and Goldman, C. R. (1990). Phosphorus and nitrogen limitation of phytoplankton growth in the freshwaters of North America: A review and critique of experimental enrichments. *Canadian Journal of fisheries and aquatic sciences*. **47**(7), 1468-1477.

Elser, J. J., Bracken, M. E., Cleland, E. E., Gruner, D.S., Harpole, W.S., Hillebrand, H., Ngai, J.T., Seabloom, E.W., Shurin, J.B. and Smith, J.E. (2007). Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. *Ecology letters*. **10**(12), 1135-1142.

Forstner, U. and Wittman, G. T. W. (1979). Metal pollution in the Aquatic Environment. *Journal of Basic Microbiology*. **21**(7), 38-41.

Francis, G. (1878). Poisonous Australian lake. *Nature*. **18**(11-12).

Gao, Y., Cornwell, J. C., Stoecker, D. K. and Owens, M. S. (2012). Effects of cyanobacterial-driven pH increases on sediment nutrient fluxes and coupled nitrification-denitrification in a shallow fresh water estuary. *Biogeosciences*. ***9***(7), 2697-2710.

Goldman, C. R. (1981). Lake Tahoe: Two decades of change in a nitrogen deficient oligotrophic lake: With 21 figures and 3 tables in the text. *Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen*. ***21***(1), 45-70.

Guilford, J. P. (1973). Fundamental statistics in psychology and education. McGraw-Hill. New York, USA. 333pp

Hao, X. and Martinez, J. (1998). Removing nitrate and ammonium from drainage water by simulation of natural biological processes. *Water Research*. ***32***(3), 936-943.

Heikkinen, K. (1990). Transport of organic and inorganic matter in river, brook and peat mining water in the drainage basin of the River Kiiminkijoki. *Aqua Fennica*. **20**(2), 143-155.

Hoyer, M. V. and Jones, J. R. (1983). Factors affecting the relation between phosphorus and chlorophyll a in midwestern reservoirs. *Canadian Journal of Fisheries and Aquatic Sciences*. **40(**2), 192-199.

Huho, J. M., Ngaira, J. K. and Ogindo, H. O. (2011). Living with drought: The Case of the Maasai Pastoralists of Northern Kenya. *Educational Research*. ***2***(1), 779-789.

Koenings, J. P. and Hooper, F. F. (1976). The influence of colloidal organic matter on iron and iron-phosphorus cycling in an acid bog lake. *Limnology and Oceanography*. **21**(5), 684-696.

Kshatriya, M., Kifugo, S. C., Msoffe, F., Neselle, M. and Said, M. (2007). Novel forms of livestock and willife integration adjacent to protected areas in Africa-Tanzania. Mapping land cover changes in Simanjiro and Monduli districts. FAO Report on GEF Tanzania project. Rome (Italy). http://hdl.handle.net/10568/1300. Accessed on April 10, 2018.

Kumar, V., Arya, S. and Dhaka, A. (2011). A Study on Physico-chemical Charactersitics of Yamuna River around Hamirpur (UP), Bundelkhand Region Central India. *International Multidisciplinary Research Journal*. **1**(5), 14-16.

Kura, N.U., Ramli, M.F., Sulaiman, W.N.A., Ibrahim, S., Aris, A.Z. and Mustapha, A. (2013). Evaluation of factors influencing the groundwater chemistry in a small tropical island of Malaysia. *International Journal of Environmental Research and Public Health*. **10**(5), 1861-1881.

Mayer, L. M. and Gloss, S. P. (1980). Buffering of silica and phosphate in a turbid river. *Limnology Oceanography*. **25**(1), 12-22.

Mbukwa, E. A., Boussiba, S., Wepener, V., Leu, S., Yuval, K., Msagati, T. A. and Mamba, B. B. (2013). Potential use of dissolved cyanobacterial DNA for monitoring toxic Microcystis cyanobacteria in filtered water. *Physics and Chemistry of the Earth, Parts A/B/C*. ***66***, 167-172.

McCarthy, M. J., Lavrentyev, P. J., Yang, L., Zhang, L., Chen, Y., Qin, B. and Gardner, W. S. (2007). Nitrogen dynamics and microbial food web structure during a summer cyanobacterial bloom in a subtropical, shallow, well-mixed, eutrophic lake (Lake Taihu, China). *Hydrobiologia*. **581**(1), 195-207.

McCarthy, M. J., James, R. T., Chen, Y., East, T. L. and Gardner, W. S. (2009). Nutrient ratios and phytoplankton community structure in the large, shallow, eutrophic, subtropical Lakes Okeechobee (Florida, USA) and Taihu (China). *Limnology*. **10**(3), 215-227.

McQuaid, N., Zamyadi, A., Prévost, M., Bird, D. F. and Dorner, S. (2011). Use of in vivo phycocyanin fluorescence to monitor potential microcystin-producing cyanobacterial biovolume in a drinking water source. *Journal of Environmental Monitoring*. **13**(2), 455-463.

Mohamed, H., Clasen, T., Njee, R. M., Malebo, H. M., Mbuligwe, S. and Brown, J. (2016). Microbiological effectiveness of household water treatment technologies under field use conditions in rural Tanzania. *Tropical Medicine & International Health*. **21**(1), 33-40.

Msoffe, F. U., Kifugo, S. C., Said, M .Y ., Neselle, M.O., Van Gardingen, P., Reid, R. S., Ogutu, J. O., Herero, M. and De Leeuw, J. (2011). Drivers and impacts of land-use change in the Maasai Steppe of northern Tanzania: An ecological, social and political analysis. *Journal of Land Use Science. **6***(4), pp.261-281.

Mtavangu, S. (2015). Intergrating constructed wetland technology with sand filter for treatment of community domestic water in rural Tanzania. Unpublished Dissertation for Award of Masters' Degree at NM-AIST. Arusha, Tanzania, pp. 7 – 30.

Ngwenya, F. (2006). Water quality trends in the Eerste River, Western cape, 1990-2005. Dissertation for Award of Doctor of Phylosophy degree at the University of the Western Cape. Cape town, South Africa. pp. 1-99.

North, R. L., Guildford, S. J., Smith, R. E. H., Havens, S. M. and Twiss, M. R. (2007). Evidence for phosphorus, nitrogen, and iron colimitation of phytoplankton communities in Lake Erie. *Limnology and Oceanography*, **52**(1), 315-328.

Odhiambo, M. (2006). Review of the literature on pastoral economics and marketing: Kenya, tanzania, uganda and the Sudan. Report prepared for the World Initiative for Sustainable Pastoralism, IUCN EARO, RECONCILE, Kenya. 19pp.

Ouyang, Y., Nkedi-Kizza, P., Wu, Q. T., Shinde, D. and Huang, C. H. (2006). Assessment of seasonal variations in surface water quality. *Water Research*.**40** (20), pp 3800-3810.

Paerl H.W. (1982). Factors limiting productivity of freshwater ecosystems. In: Advances in microbial ecology: Edited by Marshall K.C. Advances in Microbial Ecology, vol 6. Springer International Publishing, Boston, MA. pp 75-110.

Paerl, H. W. (1988). Nuisance phytoplankton blooms in coastal, estuarine, and inland waters. *Limnology and Oceanography*.**33** (4part2), 823-843.

Paschal, C., Gastory, L., Katima, J. H. Y. and Njau, K. N. (2017). Application of up-flow anaerobic sludge blanket reactor integrated with constructed wetland for treatment of banana winery effluent. *Water Practice and Technology*. **12**(3), 667-674.

Pejman, A., Bidhendi, G. N., Karbassi, A., Mehrdadi, N. and Bidhendi, M.E. (2009). Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques. *International Journal of Environmental Science & Technology*. **6**(3): 467-476.

Philemon, L. 2016. Maasai at risk as dams become waterborne breeding site. www.ippmedia.com/en/features/maasai-risk-dam. Accessed on April 11, 2018.

Polak, J. and Kentzer, A. (2004). Nitrification in the surface water of the włocławek dam reservoir. The process contribution to biochemical oxygen demand (N-BOD). *Polish Journal of Environmental Studies*. **13**(4), 415-424.

Qian, F. (2012). New approaches to the treatment of potable water in the presence of cyanobacterial blooms. Degree of Doctor of Philosophy Thesis submitted in total fulfillment of the requirements for the Degree of Doctor of Philosophy at The University of Melbourne, Australia, pp 31-260.

SAB, E. (2011). *Reactive nitrogen in the United States: An analysis of inputs, flows, consequences, and management options*. EPA-SAB-11-013. Washington, DC: Science Advisory Board, US Environmental Protection Agency (Aug 2011). http://yosemite. epa. gov/sab/sabproduct. nsf/WebBOARD/INCSupplemental. Accessed on April 10, 2018.

Sarkar, S. K., Saha, M., Takada, H., Bhattacharya, A., Mishra, P. and Bhattacharya, B. (2007). Water quality management in the lower stretch of the River Ganges, east coast of India: An approach through environmental education. *Journal of Cleaner Production*. **15**(16), pp 1559–1567.

Senay, G. B., Shafique, N. A., Autrey, B. C., Fulk, F. and Cormier, S. M. (2002). The selection of narrow wavebands for optimizing water quality monitoring on the Great Miami River, Ohio using hyperspectral remote sensor data. *Journal of Spatial Hydrology*. **1**(1), 1-22.

Schindler, D. W. (1971). Carbon, Nitrogen, and Phosphorus and the Eutrophication of Freshwater Lakes. *Journal of Phycology*. **7**(4), 321-329.

Schindler, D.W., Hecky, R.E., Findlay, D. L., Stainton, M. P., Parker, B. R., Paterson, M. J., Beaty, K.G., Lyng, M. and Kasian, S. E. M. (2008). Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. *Proceedings of the National Academy of Sciences*. **105**(32), 11254-11258.

Singh, Y., Ramteke, P. W., Mishra, S. and Shukla, P. K. (2013). Physico-chemical analysis of Yamuna River water. *International Journal of Research in Environmental Science and Technology*. **3**(2), 58-60.

Sydney Catchment Authority (SCA). (2010). Cyanobacteria risk profile. http://www.waternsw.com.au/__data/assets/ pdf_file/0020/60149/SCA-Cyanobacteria-Risk-Profile-2010.pdf . Accessed on April 23, 2016.

Tanzania Bureau of Standards. (2003). National Env. Standards Compendium - TZS 789 :2003. http://www.tzdpg.or.tz/fileadmin/_migrated/content_uploads/National_Environmental_Standards_Compendium.pdf . Accessed on April 24, 2018.

Trivedy, R. K and Goel, P. K. (1986). Chemical and biological methods for water pollution studies, Karad: *Environmental Publications*. Karad, India. pp 211-215.

UNICEF and WHO (2004). Meeting the Drinking Water and Sanitation Target: A Mid-Term Assessment of Progress. UNICEF/WHO, Geneva, Switzerland.

USEPA. (1993). Training manual for permit writers; Washington, D.C, United States Environmental Protection Agency; EPA/833/B-93/003.

Untereiner, E., Ali, G. and Stadnyk, T. (2015). Spatiotemporal variability of water quality and stable water isotopes in intensively managed prairie watersheds. *Hydrological Processes*. **29**(18), 4125-4143.

Vaishali, P. and Punita, P. (2013). Assessment of seasonal variation in water quality of River Mini, at Sindhrot, Vadodara. *International journal of environmental sciences*. **3**(5), 1424-1436

Wetzel, R. G. (Eds) (2001). Limnology: Lake and River Ecosystems. Academic Press, New York, NY. 1006pp.

WSSCC. (2004). The Campaign : WASH Facts and Figures. http://www. wsscc.org/dataweb .cfm?edit_id=292&CFID=13225&CFTOKEN =70205233. Accessed on Feb 22, 2019

WHO. (1997). Guidelines for drinking-water quality, 2nd edn, Vol. 3. Surveillance and control of community supplies 1997, World Health Organization press, Geneva, Switzerland. 238pp

WHO. (2003). Guidelines for safe recreational water environments: Coastal and fresh waters (Vol. 1). World Health Organization press. Geneva Switzerland. 219pp.

WHO. (2006). Guidelines for drinking-water quality, 3rd edn. Vol. 1. First addendum to third edition 2006, World Health Organization press, Geneva Switzerland. 515pp

www.waternsw.com.au/__data/assets/pdf_file/0020/60149/SCA-Cyanobacteria-Risk-Profile-2010.pdf . Accessed on April 20, 2018).

Zhou, F., Huang, G. H., Guo, H. C., Zhang, W. and Hao, Z. J. (2007). Spatio-temporal patterns and source apportionment of coastal water pollution in eastern Hong Kong. *Water Research*. **41** (15), pp 3429–3439.

APPENDICES

Appendix 1: Detailed Analytical Methods

Objective 1

Field measurements were done for Temperature, pH, EC, TDS, DO by using the Hanna Multiparameter probe (HI 9829). Turbidity was analyzed in the field by the Hanna turbidometer (HI 93703). TSS was done by Photometric Method. COD analysis was done by Digestion and Colorimetric method using a Multiparameter photometer (HI 83099). In this method, the sample is digested in the presence of dichromate at 150^0c for two hours. Oxidizable organic compounds reduce the dichromate (orange) ion to the chromic (green) ions. Faecal coliform was determined by Membrane Filtration Method. Sample was passed through a membrane filter membrane with a pore size 0.45 microns and 47 mm diameter (APHA, 2012). The filters were then placed on an absorbent pad (in petri dish) saturated with a MFC–agar medium with rozolic acid which is selective for coliform growth. Then the petri dish containing the filter and pad were incubated upside down for 24 hrs at 44.5^0C. After incubation the formed blue colonies were identified and counted and reported per 100ml of sample (CFU/100ml).

Objective 2

Nitrate-N was analyzed by Cadmium Reduction Method utilizing NitraVer 5 Nitrate Reagent Powder pillow. In this method, Cadmium metal reduces nitrate present in the sample to nitrite. The nitrite ion reacts in an acidic medium with sulfamic acid to form an intermediate diazonium salt. This salt couples to gentisic acid to form an amber-colored product. NO_2-N was analyzed by a Ferrous Sulfate Method using a Nitra Ver 2 Nitrite Reagent. The method uses ferrous sulfate in an acidic medium to reduce nitrite to nitrous oxide. Ferrous ions combine with the nitrous oxide to form a greenish-brown complex proportional to the nitrite present. NH_3-N was determined by Nessler Method (Nessler Reagent). The Polyvinyl Alcohol Dispensing Agent aids the color formation in the reaction of Nessler Reagent with ammonium ions. A yellow color is formed (Mineral Stabilizer complexes hardness in the sample) proportional to the ammonium concentration. Phosphorus was determined by PhosVer 3 with acid Persulfate Digestion method. Orthophosphate reacts with molybdate in acidic medium to produce a phosphomolybdate complex. Ascorbic acid then reduces the complex, giving an intense molybdenum blue color. Iron was determined by a FerroVer Method. FerroVerr Iron Reagent reacts with all soluble iron and most insoluble forms of iron in the sample, to produce soluble ferrous iron. This reacts with the 1,10-phenanthroline indicator in the reagent to form an orange color proportional to the iron concentration. Cyanobacteria were determined by indirect method utilizing phycocyanin pigment. The analysis was done between 10a.m and 3p.m. - the time with highest biomass (Ahn, *et al*., 2008). Phycocyanin pigment which is unique to cyanobacteria was analysed in situ by using *Aqua*Fluor model 8000-01(serial # 803247). World Health Organization (WHO) water quality guidelines (Ahn *et al*., 2008; Brient*et al*., 2008; McQuaid *et al*., 2011), were used to interpret the phycocyanin concentration on the basis that a concentration of 30 µg/L is equivalent to the WHO alert level of 20 000 cyanobacterial cells/mL, and less than 30 µg/L means that the number of cyanobacterial cells/mL is below the alert level.

Appendix 2: Table of Results

(a) Field Parameter – Outlet

Sampling Date	Temp(◦C)	pH	DO_mg/l	EC_µS/cm	TDS _mg/l	Turb _NTU	TSS_mg/l
08-Jan-17	27.15	8.33	5.88	1274	830	44700	44900
29-Jan-17	24	7.8	7.8	308	163	14800	13300
06-Feb-17	23.71	7.53	5.11	332	166	7950	10300
13-Feb-17	22.98	8.1	6.01	369	184	10500	10500
07-Mar-17	25	8.3	4.03	305	153	6000	9250
20-Mar-17	33.41	8.6	2.54	243	149	7550	10900
03-Apr-17	23.39	8.36	3.92	341	170	12100	18400
24-Apr-17	21	8.57	5	390	195	5750	9650
06-May-17	22.39	8.8	6.9	412	205	5100	7470
29-May-17	23.5	8.54	2.6	250	141	2920	3820
01-Aug-17	19.55	7.67	4.71	1322	856	1255	3875
13-Aug-17	26.08	8.2	1.4	1595	1036	1010	2630
31-Aug-17	25.25	9.81	8.05	3908	2544	800	1750
13-Sep-17	26.43	8.37	2.36	5603	3642	4330	12000
25-Sep-17	26.86	8.35	1	5766	3748	670	6090

(b) Field Parameter – Inlet

Sampling Date	Temp (◦C)	pH	DO_mg/l	EC_µS/cm	TDS _mg/l	Turbidity	TSS_mg/l
08-Jan-17	26.8	8.38	6.52	1356	882	45300	46600
29-Jan-17	25	7.01	8.8	390	195	53300	46200
06-Feb-17	28.36	7.71	4.34	372	187	10100	10200
13-Feb-17	26	8.28	6.18	381	189	10900	11700
07-Mar-17	25	8.31	4.2	344	153	6800	14800
20-Mar-17	32.28	8.4	2.67	399	200	3950	7000
03-Apr-17	25.42	8.17	3.91	340	170	8400	13400
24-Apr-17	25.09	8.49	5.05	393	196	6300	10200
06-May-17	28.32	8.37	7.21	401	201	5730	10230
29-May-17	24	8.68	3	256	146	3030	4480
01-Aug-17	23.25	7.67	7.76	1361	822	645	2400
13-Aug-17	25.3	8.27	3	1571	1023	2020	5440
31-Aug-17	26.2	8.42	5.21	4274	2777	2080	6125
13-Sep-17	25.25	8.96	2.5	5398	3508	1380	3800
25-Sep-17	26.15	8.15	3.64	5802	3855	204	11525

(c) Chemical and biological Parameter – Inlet

SN	Sampling Date	NO_3-N (mg/l)	NO_3 (mg/l)	NO_2-N (mg/)l	NH3-N (mg/l)	PO_4^{3-}(mg/l)	COD (mg/l)	Fe (T) (mg/l)	FC_CFU/100ml	Phycocyanin (µg/l)
1	08-Jan-17	11.7	51.9	0.025	0.14	0.52	8.7	1380	8000	495
2	29-Jan-17	10.5	46.6	0.117	3.46	0.08	6.59	1000	8810	320.3
3	06-Feb-17	39.5	174	0.02	1.56	0.99	14.5	56	2000	495
4	13-Feb-17	22	99	<0.001	8.4	0.42	8.17	71	1990	485.9
5	07-Mar-17	1715	7590	<0.001	103	3.5	37.44	25.5	1000	60.61
6	20-Mar-17	175	774.69	<0.001	78	2.5	35.59	35.5	5700	278.7
7	03-Apr-17	300	1313	11.2	213	8	5.54	167	1000	214
8	24-Apr-17	120	520	<0.001	142.5	4.5	87	972	760	414.8
9	06-May-17	27	114	1.2	9.3	3.9	50.86	38.5	1520	450.6
10	29-May-17	0.6	3	<0.001	6.28	0.48	21.04	35.3	1350	139.2
11	01-Aug-17	292	1291	19.25	0.52	0.5	1.57	17	100.66	69.82
12	13-Aug-17	52.5	232.5	6.4	1.2	0.53	2	15	330.39	89.06
13	31-Aug-17	4	18	2.9	4	2.88	<0.7	14	340.38	93.22
14	13-Sep-17	270	1208	2.4	5.9	3.81	1.7	13.5	220.81	160.3
15	25-Sep-17	54	240	2.5	2.9	0.31	1.9	13	30	61.51

(d) Chemical and biological Parameter – Outlet

S/N	Sampling Date	NO3-N (mg/l)	NO3 (mg/l)	$N0_2$-N_mg/l	NH_3-N_mg/l	PO_4^3- (mg/)l	COD (mg/l)	Iron(T) mg/l	FC_CFU/100ml	Phycocyanin (µg/l)
1	08-Jan-17	7.5	33.4	0.051	0.16	0.6	2.1	1300	7380	490
2	29-Jan-17	6.3	27.87	0.054	1.88	0.49	2.72	875	1870	276.9
3	06-Feb-17	30	132.7	0.031	2.58	0.84	2.1	15.5	1700	475.4
4	13-Feb-17	35	154	<0.001	8.4	0.06	2.02	78	1500	484.9
5	07-Mar-17	15	60	<0.001	91	2	29.1	49.9	920	424.8
6	20-Mar-17	300	7700	<0.001	171.07	2	22.88	71	980	452.4
7	03-Apr-17	290	1290	2.8	270	10	2.37	100	2000	38.07
8	24-Apr-17	105	465	<0.001	142.5	4	19.41	892	1520	430.9
9	06-May-17	351	1560	<0.001	8.4	5.7	17.28	35.5	1200	442.5
10	29-May-17	3.6	15.6	<0.001	5.96	0.72	3.93	34	1220	139.2
11	01-Aug-17	30	130	0.209	27	0.6743	1.4	26	201	69.42
12	13-Aug-17	512	2262	30	3.4	1.9	2.7	21	160.69	125.2
13	31-Aug-17	60	268	230	7.1	0.61	<0.7	20	130	175.7
14	13-Sep-17	54	238	220	2.2	5.3	1.95	20	710.5	19.85
15	25-Sep-17	51	226	290	2.7	15.2	2.1	18	110	130

Appendix 3: Correlation Coefficient Tables

(a) Correlation coefficient table for outlet

		NO3-N	NO2-N	NH3-N (mg/l)	PO43	COD	Fe (T)	FC	Phycocyanin	Temp	pH	DO	EC_µS/cm	TDS	Turbidity	TSS_mg/l
NO3-N	Pearson Corr.															
	Sig.	--														
NO2-N	Pearson Corr.	0.74506														
	Sig.	0.01341	--													
NH3-N (mg/l)	Pearson Corr.	0.38927	0.3596													
	Sig.	0.15153	0.30745	--												
PO43	Pearson Corr.	0.29317	0.18807	0.82723												
	Sig.	0.28893	0.60284	1.42E-04	--											
COD	Pearson Corr.	0.16488	-0.32748	0.42919	0.38617											
	Sig.	0.57324	0.38965	0.12566	0.17263	--										
Fe (T)	Pearson Corr.	-0.19513	-0.35776	0.08509	-0.09813	0.219										
	Sig.	0.48585	0.31011	0.76304	0.72789	0.45192	--									
FC	Pearson Corr.	-0.18851	-0.44667	-0.1273	-0.30121	-0.07444	0.70065									
	Sig.	0.50105	0.19562	0.6512	0.27528	0.80033	0.00362	--								
Phycocyanin	Pearson Corr.	-0.37962	-0.55026	-0.01657	-0.02408	0.32247	0.50618	0.49								
	Sig.	0.16283	0.09933	0.95326	0.9321	0.26082	0.0542	0.06372	--							
Temp	Pearson Corr.	-0.17311	-0.71886	0.02195	0.0719	0.22302	-0.08737	0.35003	0.42069							
	Sig.	0.53725	0.01915	0.93811	0.799	0.44343	0.75686	0.2009	0.11842	--						
pH	Pearson Corr.	0.07974	-0.12088	0.13378	0.34873	0.27182	-0.24325	-0.42401	-0.12091	0.09508						
	Sig.	0.77757	0.7394	0.63456	0.2027	0.34716	0.38233	0.11524	0.66775	0.73607	--					
DO	Pearson Corr.	-0.15312	0.07565	-0.24239	-0.24695	0.01853	0.47358	0.42229	0.38095	-0.20906	-0.64891					
	Sig.	0.58588	0.83545	0.38408	0.3749	0.94987	0.07456	0.11687	0.16123	0.45461	0.00886	--				
EC_µS/cm	Pearson Corr.	-0.13788	-0.1428	-0.34527	-0.0772	-0.40231	-0.23117	-0.35013	-0.47927	-0.12266	0.29857	-0.29326				
	Sig.	0.62411	0.69392	0.20752	0.78449	0.15385	0.40712	0.20077	0.07066	0.6632	0.27972	0.28877	--			
TDS	Pearson Corr.	-0.14395	-0.1478	-0.34807	-0.08429	-0.40534	-0.2271	-0.34701	-0.47894	-0.12259	0.29935	-0.29714	0.99983			
	Sig.	0.60878	0.68366	0.20361	0.7652	0.15048	0.41565	0.20509	0.07088	0.66338	0.2784	0.28215	0	--		
Turbidity	Pearson Corr.	-0.15251	-0.41226	-0.14262	-0.28273	-0.16078	0.82134	0.89009	0.47148	-0.0167	-0.53083	0.59846	-0.27789	-0.27461		
	Sig.	0.58739	0.23645	0.61211	0.30724	0.58295	1.74E-04	8.78E-06	0.07603	0.9529	0.04176	0.01843	0.31595	0.32193	--	
TSS_mg/l	Pearson Corr.	-0.06739	-0.4433	-0.08082	-0.23191	-0.13586	0.8325	0.85518	0.4231	-0.00285	-0.47048	0.55255	-0.20457	-0.19974	0.97575	
	Sig.	0.81139	0.19943	0.77462	0.40558	0.64329	1.17E-04	4.83E-05	0.11609	0.99195	0.07674	0.03268	0.46456	0.4754	5.88E-10	--

(b) Correlation coefficient table for outlet

		NO3-N	**NO2-N**	**NH3-N (mg/l)**	**PO43**	**COD**	**Fe (T)**	**FC**	**Phycocyanon**	**Temp**	**pH**	**DO**	**EC_µS/cm**	**TDS**	**Turbidity**	**TSS_mg/l**
NO3-N	Pearson Corr.															
	Sig.	--														
NO2-N	Pearson Corr.	-0.19439														
	Sig.	0.61625	--													
NH3-N (mg/l)	Pearson Corr.	0.33109	-0.27103													
	Sig.	0.22803	0.48056	--												
PO43	Pearson Corr.	0.1999	0.52881	0.2943												
	Sig.	0.47503	0.14325	0.28699	--											
COD	Pearson Corr.	0.17394	-0.16455	0.40797	-0.06717											
	Sig.	0.55204	0.697	0.1476	0.81953	--										
Fe (T)	Pearson Corr.	-0.26695	-0.40672	-0.00333	-0.20729	-0.02716										
	Sig.	0.33615	0.27732	0.9906	0.45852	0.92657	--									
FC	Pearson Corr.	-0.22398	-0.43947	-0.00797	-0.20611	-0.1486	0.77923									
	Sig.	0.42228	0.23658	0.97751	0.46113	0.61214	6.16E-04	--								
Phycocyanin	Pearson Corr.	-0.09724	-0.39222	-0.02398	-0.37695	0.50266	0.37986	0.44254								
	Sig.	0.73027	0.29645	0.93241	0.16605	0.06696	0.16254	0.09857	--							
Temp	Pearson Corr.	0.24016	0.49621	0.1244	0.08901	0.22343	-0.0301	0.11665	0.13395							
	Sig.	0.3886	0.17425	0.6587	0.75242	0.44259	0.9152	0.67886	0.63411	--						
pH	Pearson Corr.	0.17074	0.61189	0.09654	0.09651	0.50286	-0.10073	-0.12796	-0.06682	0.23973						
	Sig.	0.54292	0.0799	0.73216	0.73222	0.06683	0.72096	0.64949	0.81296	0.38946	--					
DO	Pearson Corr.	-0.28624	-0.2949	-0.16408	-0.46017	0.0402	0.38727	0.28962	0.40835	-0.38486	0.18705					
	Sig.	0.301	0.44109	0.55899	0.08435	0.89146	0.15382	0.29508	0.13076	0.15662	0.50444	--				
EC_µS/cm	Pearson Corr.	-0.15657	0.96096	-0.35095	0.50287	-0.34853	-0.22418	-0.2685	-0.54175	0.23205	0.29888	-0.3185				
	Sig.	0.57735	3.73E-05	0.19964	0.05605	0.22199	0.42184	0.33324	0.03698	0.40529	0.2792	0.24727	--			
TDS	Pearson Corr.	-0.15536	0.95937	-0.35307	0.49634	-0.35133	-0.22203	-0.26519	-0.54445	0.23872	0.29904	-0.32173	0.99988			
	Sig.	0.58033	4.28E-05	0.19676	0.05985	0.21805	0.42642	0.33947	0.03587	0.39154	0.27893	0.24226	0	--		
Turbidity	Pearson Corr.	-0.2177	-0.44296	-0.00336	-0.2129	-0.16067	0.7818	0.98279	0.42915	0.18492	-0.15612	0.31352	-0.24142	-0.2376		
	Sig.	0.43573	0.23244	0.99052	0.44616	0.5832	5.75E-04	6.42E-11	0.11042	0.5094	0.57848	0.25516	0.38604	0.39384	--	
TSS_mg/l	Pearson Corr.	-0.18651	-0.36691	0.10623	-0.05591	-0.14499	0.73398	0.96217	0.34771	0.2241	-0.15093	0.18979	-0.13993	-0.1371	0.9742	
	Sig.	0.50569	0.33139	0.70632	0.84311	0.62093	0.00184	1.02E-08	0.20411	0.42203	0.59132	0.49811	0.6189	0.62609	8.74E-10	--

RESEARCH OUTPUT

© IWA Publishing 2018
712

Water Practice & Technology Vol 13 No 3
doi: 10.2166/wpt.2018.083

Water quality in earthen dams and potential health impacts: case of Nadosoito Dam, Tanzania

N. Eliakimu, R. L. Machunda and K. N. Njau*

The Nelson Mandela African Institution of Science and Technology, P.O. Box 447, Arusha, Tanzania

*Corresponding author. E-mail: karoli.njau@nm-aist.ac.tz

Abstract

The aim of the study was to assess seasonal water quality variations in an earthen dam and their potential impact on the health of those using the water for domestic purposes. High values of chemical oxygen demand, from <0.7 to 87 mg/l, and turbidity, from 204 to 53,300 NTU, were reported. Turbidity and total suspended solids were the highest at the onset of rainfall, and generally declined from the wet to the dry season. Ammonia concentrations ranged from 0.14 to 270 mg/l and nitrate from 0.6 to 1,715 mg-N/l, and were highest towards the end of wet season, while NO_2-N was highest (290 mg/l) in the dry season. There were some notably high phycocyanin (PC) pigment values (19.9 to 495 μg/l) unique to cyanobacteria, well above the WHO alert level of 30 μg/l. PC is associated with a variety of toxins affecting humans and animals. Possible sources of pollutants include animal droppings/urine and runoff from farms applying fertilisers. A further aim was to assess water treatability with a pilot inclined plate settler system for pollutants and microbial removal. The results of this study suggest that water treatment systems must be designed to take care of the worst influent water quality conditions.

Key words: cyanobacteria, earthen dam, health impacts, water quality

INTRODUCTION

Nadosoito dam in Tanzania is faced with water quality issues that change through the year. It has been said that water from the dam is unpalatable (sour), especially during the dry season, and also has an odour (personal communication). Over 6,000 inhabitants of Arkatani and others from the surrounding villages depend on the dam for domestic supplies and watering animals (over 10,000 cattle, goats, sheep and donkeys), making it very important. It is reported that there are numbers of livestock deaths at some periods of the year. High turbidity harbours microorganisms including pathogens, thus posing a risk to human health (Senay *et al.* 2002). Despite the water's characteristic turbidity, the dam is shared by humans, livestock and wild animals, making it a potential source of zoonotic diseases. This also has the potential to add nutrients and organic matter when the animals drink from the dam.

Villagers report that the water situation in the area is terrible and worsens during dry season. Vaishali & Punita (2013) explain that waters with a high total dissolved solids (TDS) content are unpalatable and potentially unhealthy. Francis (1878) made the first report of cyanobacterial poisoning, which led to the deaths of cattle, sheep, dogs, horses and pigs after they drank water contaminated with cyanobacteria in Lake Alexandrina, Australia. Since then, many cases of farm animals, waterfowl and wild animals being poisoned by cyanobacterial water after swimming or drinking have been reported. The deaths of cattle reported in the Nadosoito dam area could well be associated with cyanobacteria.

Microorganism persistence in water is affected by several factors, including temperature. Their decay is usually faster at higher temperatures and may be enhanced by the UV radiation in sunlight

Water Practice & Technology Vol 13 No 3
doi: 10.2166/wpt.2018.083

acting near the water surface (WHO 2006). The WHO guideline for drinking water (2006) warns that, between 25 and 50 °C, a wide variety of microorganisms proliferate. The pH of the water affects the solubility of many toxic and nutritive chemicals, so that the availability of these substances to aquatic organisms is affected. As acidity increases, most metals become more water soluble and more toxic, while ammonia becomes more toxic with slight increases in pH (Vaishali & Punita 2013). The water's pH may affect its treatment and is an important parameter for the treatment system. For instance, more alkaline waters require longer contact time or higher free residual chlorine levels at the end of contact time for adequate disinfection (0.4 to 0.5 mg-Cl/l at pH 6 to 8, rising to 0.6 mg-Cl/l at pH 8 to 9); chlorination may be ineffective above pH 9 (WHO 2006).

The importance of Nadosoito dam for domestic and livestock use prompted this study. It was recognised that there was a need to understand the water quality variations and their health impacts, as well as selected microorganisms and pollutants (NO_3-N, NO_2-N, NH_3-N, P and Fe).

MATERIALS AND METHODS

Site description

Nadosoito Dam is located near Arkatani Village, Sepeko ward, Monduli district, Arusha, Tanzania (Figure 1), with geographical coordinates, 03° 18′ S and 36° 27′ E. Two small seasonal streams deliver water to the dam, with one removing it during the rainy season.

A census in 2012 by the United Republic of Tanzania (URT) Bureau of Statistics recorded 158,929 people in Monduli district, of which, Sepeko ward recorded 16,720 people (URT 2012). The population (majority Maasai tribe) comprises mainly agro-pastoralists. They were previously purely pastoralist but agriculture is practiced nowadays as a strategy to cope with population increase and the effects of climate change on their livestock. Sepeko is largely grassy lowland with scattered shrubs, used for grazing.

Being a nomadic tribe, the Maasai constantly move their herds searching for better grazing and water sources. Some, especially women and children, stay at home and move only during severe droughts that lead to loss of water and grass. Most of the bean and maize farms, which are only rain-fed, are located in the lower part on the south-west side of the dam. There are hills north of the dam and residential areas scattered around it.

The area is frequently drought-stricken and people depend on the dam as the major water source. Average annual rainfall is 650 mm and the range in the long-term rainfall trend analysis (1984 and 2000) extends from <500 to >600 mm (Msoffe *et al.* 2011). The dam water is characteristically turbid with very fine clay particles, which settle slowly. An inclined plate settler (IPS) combined with a constructed wetland project by the Nelson Mandela African Institution of Science and Technology (NM-AIST) are located at the dam to treat turbid water.

Sample collection

Two points were selected for sample collection from the dam to represent the water quality: the spillway (SW) and the waterway entry point (WWE). Samples were collected twice a month, in selected months in the wet and dry season in 2017, to ascertain water quality variation and treatability from the onset of rainfall to the end of the dry season, and the causes of animal deaths with respect to each season. The wet months selected were January through May, while the dry months were August and September. All physico-chemical samples were collected in sampling bottles, and preserved as per the standard methods for examination of water and wastewater (APHA 2012). Except for those containing preservatives (e.g. for Fe), the bottles were rinsed three times with the sampled field water before sample collection. They were then stored in iced cool boxes with blue

Water Practice & Technology Vol 13 No 3
doi: 10.2166/wpt.2018.083

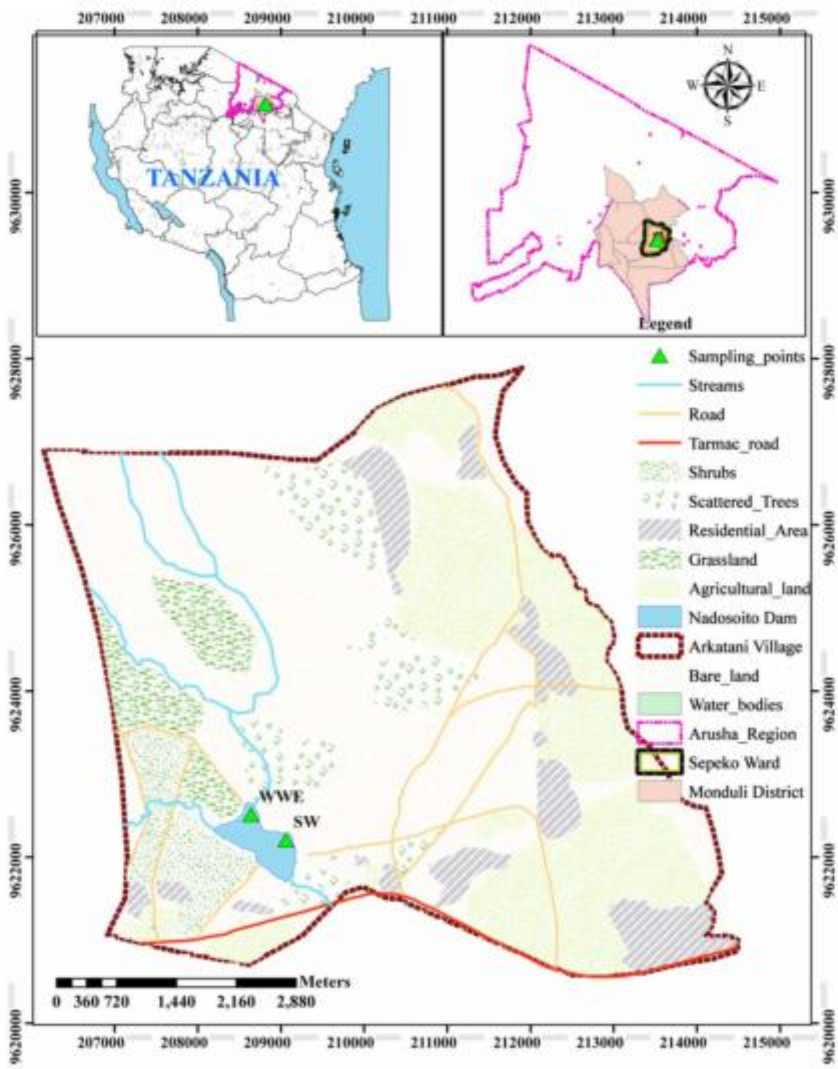


Figure 1 | Location of Nadosoito Dam.

ice cubes at 4 °C before delivery to the NM-AIST laboratory for analysis. Samples were taken at the WWE and SW to determine the changes occurring as water moves between the two. This was necessary to try to determine an appropriate location to draw water for treatment.

Physico-chemical analysis

Most physical-chemical parameters were analysed in the field; pH, temperature, dissolved oxygen (DO), electrical conductivity (EC) and TDS, using a HANNA Multiparameter (HI 9829, HANNA

Water Practice & Technology Vol 13 No 3
doi: 10.2166/wpt.2018.083

Instruments, Woonsocket, RI, USA). Turbidity was determined with a HANNA Turbidimeter (HI 93703), after dilution of the samples (100 times, in most cases, in the wet season), as the raw water was too turbid for the equipment. TSS were determined by direct measurement with a spectrophotometer (HACH DR 2800, Hach, Loveland, CO, USA). Nitrogenous species (NO_2-N, NO_3-N, NH_3-N), P and Fe were determined at the NM-AIST laboratory with a HACH DR 2800 spectrophotometer. Chemical oxygen demand (COD) was determined by the reactor digestion method using a HACH COD digester (DRB 200) and a multiparameter photometer (HI 83099), as per the manufacturer's instructions and the standard methods for examination of water and wastewater (APHA 2012). Phycocyanin (PC) pigment unique to cyanobacteria was analysed *in situ* using *Aqua*Fluor model 8000-01 (Turner Designs, San Jose, CA, USA, serial # 803247). WHO water quality guidelines (Brient *et al.* 2008), were used to interpret the PC concentration on the basis that a concentration of 30 μg/L is equivalent to the WHO alert level of 20,000 cyanobacterial cells/mL, and less than 30 μg/L means that the number of cyanobacterial cells/mL is below the alert level.

RESULTS AND DISCUSSION

The general trend was for most physical parameters (e.g. turbidity, TSS) to decline between the WWE and SW. Some parameters, like turbidity, increased with increasing rainfall (due to the high influx of suspended materials) while others, e.g. EC and TDS, declined with rainfall as a result of dilution. Nutrient concentrations (e.g. nitrate) were higher in the wet than the dry season, while nitrite and phosphate concentrations were higher in the dry than the wet season.

Electrical conductivity, total dissolved solids and total suspended solids

EC varied greatly between the wet and dry seasons, with maxima of 1,356 and 5,802 μS/cm respectively in the wet and dry seasons. The wet season maximum was very different from the other wet season results and was determined at the onset of rainfall (January 2017). This arose because of the transfer into the dam of organic and inorganic materials that had accumulated in the catchment. Other EC results from the wet season were in the range 243 to 412 μS/cm. These lower values arise mainly because of dilution by rainwater. The highest EC values were read, in both seasons, at the WWE sampling site. The wet season variation is due to rainwater dilution – only light rain had fallen by the time of the first sampling in January. The dry season variation was caused by the high rates of evaporation, which reduced the volume of water and concentrated the dissolved solids. EC is used only to give an indication of possible water quality problems.

TDS varied from 141 to 882 mg/l, and from 822 to 3,855 mg/l, in the wet and dry seasons respectively. The wet season TDS maximum was found at the WWE. The maximum TDS – 3,855 mg/l – was also obtained at the WWE at the final sampling (dry season), in September 2017. There was evidence of erosion on the sides of the dam during the rainy season, at that time, indicating that large amounts of sediment had been discharged into the water, leading to high TSS and TDS concentrations. Erosion is likely to increase the TDS in water because it enhances the supply and transport of potentially soluble ionic components from the catchment into the dam.

Water with TDS concentrations below 1,000 mg/l is usually acceptable for domestic use, although this may vary according to circumstances (WHO 2003). The TDS concentration in the dam was consistently below 1,000 mg/l throughout the wet season, and so within the acceptable limit. All dry season samples, apart from the first (August 1, 2017), had concentrations exceeding 1,000 mg-TDS/l, which might explain the objectionable taste of the water then, at least in part. Heavy rainfall diluted the dam water and the TDS concentration decreased in the wet season, while evaporation caused the TDS to increase in the dry season (Figure 2).

Water Practice & Technology Vol 13 No 3
doi: 10.2166/wpt.2018.083

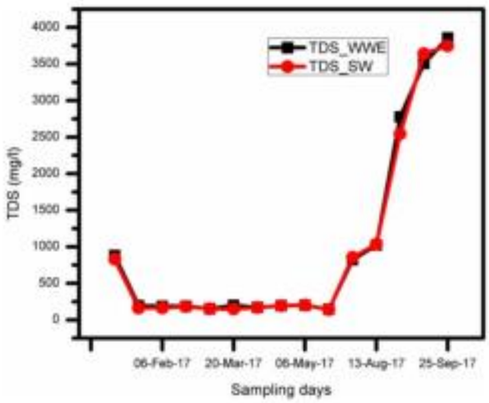


Figure 2 | TDS variation at the two sampling sites from the wet to the dry season.

TSS concentrations ranged from 3,820 to 46,600 mg/l and 1,750 to 12,000 mg/l, in the wet and dry seasons respectively, at both sampling points. The general trend shows a decline from the wet to the dry season (Figure 3). TSS is a significant indicator of potential pollution because some pollutants and microorganisms can adhere to the suspended particles.

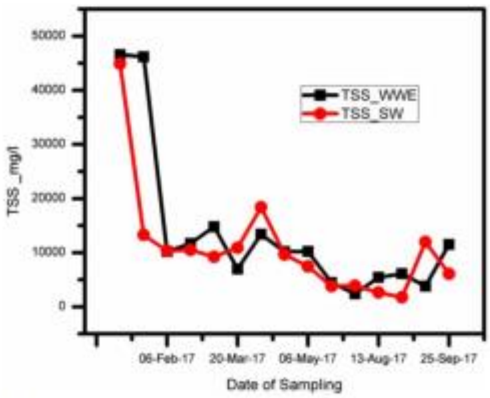


Figure 3 | TSS variation at the two sampling sites from the wet to the dry season.

Temperature of the water in the dam ranged from 19.55 °C (1 August) to 33.41 °C (20 March), with both measurements (max and min) taken at the SW. Temperature affects some physico-chemical properties of water (e.g. DO), which are discussed with the respective water quality parameters.

pH ranged from 7.01 to 9.81 across the seasons, with a wet season range from 7.01 to 8.8, and dry season range from 7.67 to 9.81 (Tables 1 and 2). The highest wet season pH (8.8) occurred in May, and the highest in the dry season (9.81) in August, both at the SW. The water was generally more alkaline in the dry season than the wet.

Turbidity is another indicator of the amount of material suspended in water, and is a measure of the amount of light scattered or absorbed as it passes through the water column. It is a measure of water clarity describing how far the light will go as it passes through water. Suspended silt and clay, organic

Water Practice & Technology Vol 13 No 3
doi: 10.2166/wpt.2018.083

Table 1 | Descriptive statistics – WWE

Parameter	Min	Max	Parameter	Min	Max
Wet season (January to May)			Dry season (August to September)		
Temp (°C)	24	32.28	Temp (°C)	23.25	26.2
pH	7.01	8.68	pH	7.67	8.96
DO (mg/l)	2.67	8.8	DO (mg/l)	2.5	7.76
EC (μS/cm)	256	1,356	EC (μS/cm)	1,361	5,802
TDS (mg/l)	146	882	TDS (mg/l)	822	3,855
Turb (NTU)	3,030	53,300	Turb (NTU)	204	2,080
TSS (mg/l)	4,480	46,600	TSS (mg/l)	2,400	11,525
NO_3-N (mg/l)	0.6	1,715	NO_3-N (mg/l)	4	292
NO_2-N (mg/l)	<LoD	11.2	NO_2-N (mg/l)	2.4	19.25
NH_3-N (mg/l)	0.14	213	NH_3-N (mg/l)	0.52	5.9
PO_4^{3-} (mg/l)	0.08	8	PO_4^{3-} (mg/l)	0.31	3.81
COD (mg/l)	5.54	87	COD (mg/l)	<LoD	2
Total iron (mg/l)	25.5	1,380	Iron (mg/l)	13	17
FC (CFU/100 ml)	760	8,810	FC (CFU/100 ml)	30	340.38
PC (μg/l)	60.61	495	PC (μg/l)	61.51	160.3

LoD: limit of detection.

Table 2 | Descriptive statistics – SW

Parameter	Min	Max	Parameter	Min	Max
Wet season (January to May)			Dry season (August to September)		
Temp (°C)	21	33.41	Temp (°C)	19.55	26.86
pH	7.53	8.8	pH	7.67	9.81
DO (mg/l)	2.54	7.8	DO (mg/l)	1	8.05
EC (μS/cm)	243	1,274	EC (μS/cm)	1,322	5,766
TDS (mg/l)	141	830	TDS (mg/l)	856	3,748
Turb (NTU)	2,920	44,700	Turb (NTU)	670	4,330
TSS (mg/l)	3,820	44,900	TSS (mg/l)	1,750	12,000
NO_3-N (mg/l)	3.6	351	NO_3-N (mg/l)	30	512
NO_2-N (mg/l)	<LoD	2.8	NO_2-N (mg/l)	0.209	290
NH_3-N (mg/l)	0.16	270	NH_3-N (mg/l	2.2	27
PO_4^{3-} (mg/l)	0.06	10	PO_4^{3-} (mg/l)	0.61	15.2
COD (mg/l)	2.02	29.1	COD (mg/l)	<LoD	2.7
Iron (mg/l)	15.5	1,300	Iron (mg/l)	18	26
FC (CFU/100 ml)	920	7,380	FC (CFU/100 ml)	110	710.5
PC (μg/l)	38.1	490	PC (μg/l)	19.9	175.7

matter, and plankton all contribute to turbidity. Turbidity at the dam ranged from 2,920 to 53,300 NTU in the wet season, with mean values of 15,381 NTU at the WWE and 11,737 NTU at the SW (Tables 1 and 2). In the dry season, the turbidity ranged from 204 to 4,330 NTU, with means of 1,265 NTU at the WWE and 1,613 at the SW. Such values indicate the potential presence of harmful contaminants.

Like TSS, turbidity was lower in the wet than the dry season, because settlement of solids is possible in the latter. WHO recommends <5 NTU as an acceptable turbidity range for drinking water (WHO 2006) while the Tanzania Standards for drinking water (TZS) recommends a range of 5 to 25 NTU

Water Practice & Technology Vol 13 No 3
doi: 10.2166/wpt.2018.083

(TZS 2003). For effective disinfection, it is recommended that turbidity is consistently below 5 NTU and preferably below 1 (WHO 1997). The values obtained are far above the recommended range and the water requires treatment before consumption. Turbidity varied in line with TSS at both sampling locations (Figure 4). In the context of the IPS it was noted that pre-treatment of such high turbidity water will require more settling/sedimentation time.

DO concentrations ranged from 2.54 to 8.8 mg/l in the wet season and 1 to 8.05 mg/l in the dry season. The maximum concentration of DO was found at the WWE in the wet season (January 2017) (Table 1) when the temperature was 25 °C. The lowest DO, also at the WWE, was observed at the end of dry season (September) (Table 1). DO is an important parameter in water quality assessment, and reflects the physical and biological processes prevailing in the water (Trivedy & Goel 1984). Organic pollution, for instance, tends to remove much of the DO in aerobic biological decay, decreasing the amount in the water (Chhatwal 2011). Other studies have related low DO concentrations to aesthetically displeasing colours, tastes and odours in water. DO depletion in water supplies can encourage microbial reduction of nitrate to nitrite and an increase in the concentration of ferrous

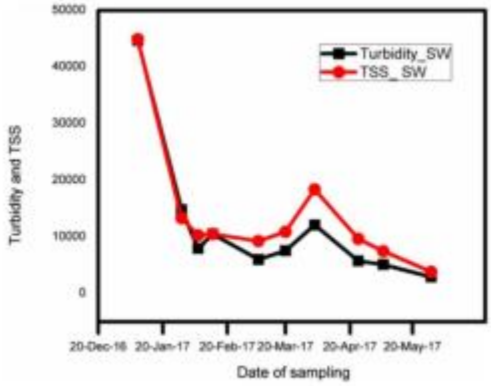


Figure 4 | Turbidity and TSS variation trend for the wet season (SW).

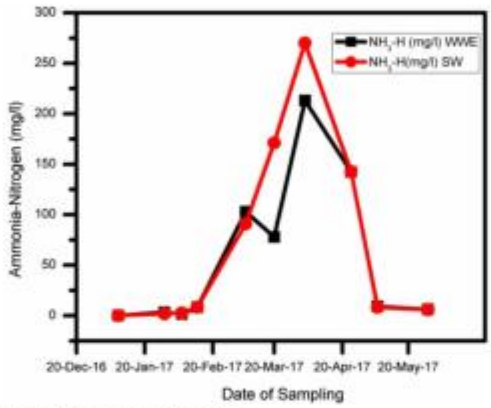


Figure 5 | Ammoniacal-Nitrogen variation in the wet season.

Water Practice & Technology Vol 13 No 3
doi: 10.2166/wpt.2018.083

iron in solution, with subsequent discoloration at the tap when the water is aerated (WHO 2006). A similar relationship was established in this study, whereby, when the DO concentration was at its lowest the nitrite concentration was at its maximum (290 mg/l) – at the end of the dry season (September). No health-based guideline value is recommended for DO (WHO 2006).

COD is a measure of the amount of oxygen required to oxidize dissolved organic and inorganic material, and is commonly used as an indirect measure of the concentration of organic compounds in water (Kumar *et al.* 2011). The COD level at the two sampling locations ranged from <0.7 to 87 mg/l. The minimum was obtained at both locations on 1 August, in the dry season, the maximum at the WWE in April (Table 1). The highest COD level at the SW was 29.1 mg/l, occurred on 7 March (Table 2). The maximum and minimum levels generally arise from the material loads brought into the dam by surface runoff and subsequent settling, respectively. This is due to the fact that much material is brought into the dam by the surface runoff and the rivers during the wet season, while no material is brought into it during the dry season, since the rivers to the dam are seasonal. The general trend for COD to decrease from the WWE to the SW, and from the wet to the dry season, is accounted for by several factors, including material sedimentation and possible removal of organic substrate that is coupled with the formation of the biomass and the consumption of DO (Orhon *et al.* 2009).

Ammoniacal–nitrogen (NH_3-N)

The most important source of ammonia in the water in the dam is the ammonification of organic matter. Animal and human excreta contain large proportions of nitrogenous matter, so their presence and decomposition in water tends to increase ammonia concentrations. Ammonia's presence in waters provides chemical evidence of organic pollution (Trivedy & Goel 1984). The concentration of ammonia (NH_3-N) ranged from 0.14 to 270 mg/l in the wet season and 2.2 to 27 mg/l in the dry. The concentration increased with increasing rainfall in the wet season at both sampling locations (Figure 5), with the highest value occurring at the SW in April (Table 2). The maximum concentration at the WWE was 213 mg/l, also in April (Table 1).

Standard deviations of 74.967 and 95.257 mg/l was obtained at the WWE and SW, respectively, in the wet season, while the dry season values were 7.21 and 10.53 mg/l at the WWE and SW, respectively. The high deviation in the wet season was a result of a very high ammonia value obtained during April 2017 sampling as compared to other sampling events. The threshold odour concentration of ammonia at alkaline pH is approximately 1.5 mg/l, and a taste threshold of 35 mg/l has been proposed for the ammonium cation – beyond that, it can cause taste and odour problems (WHO 2006).

Nitrate (NO_3-N) was generally higher at the WWE than SW in samples taken in the wet season. The concentration was below 10 mg-N/l (the WHO guideline level for drinking water) in only two samples (both taken in January) from the SW. In the dry season, all determinations of NO_3-N, except one (in August), at the WWE – 4 mg/l – exceeded the guideline value. This means that infants and pregnant or nursing women are potentially exposed to methaemoglobinaemia (WHO 2006) since they currently use the water untreated. The highest level reported was 1,715 mg-N/l, which was taken at the WWE in March (Table 1). NO_3-N was higher at the WWE than SW for all but four sampling sessions – the latter were 13 February, 20 March, and 6 and 29 May 2017, all in the wet season.

The maximum NO_3-N concentration in the dry season was 512 mg-N/l, in the August sample from the SW. There was significant variation in NO_3-N concentrations between the sampling sessions, with standard deviations of 207 and 135 mg-N/l for the SW and WWE, respectively.

Nitrite is more toxic than nitrate. The WHO provisional long-term exposure guideline for NO_2-N is 0.2 mg-N/l (WHO 2006). As for nitrate, the presence of nitrite in water is associated with methaemoglobinaemia, especially in bottle-fed infants (WHO 2006). With a single exception – 3 April at the WWE –all wet season samples at the WWE reported NO_2-N below the WHO guideline. In the dry season all samples from both locations reported NO_2-N concentrations significantly above the WHO guideline. The highest concentration – 290 mg-N/l – was obtained at the SW on 25 September and the minimum – 0.209 mg-N/l – on 1 August. Clearly, the dam water will require effective treatment to remove nitrite to the level recommended for drinking – especially in the dry season.

Phosphate (PO_4^{3-}) concentrations varied in the wet season from 0.06 to 10 mg/l at the two sampling points. PO_4^{3-} concentrations were generally fairly similar at the WWE and SW (Tables 1 and 2). The higher concentrations, 2 to 10 mg-P/l were recorded between March and May when there were long periods of rainfall. Phosphate concentrations were higher in the dry than the wet season. The minimum and maximum dry season concentrations were 0.31 and 15.2 mg-P/l respectively (Tables 1 and 2) – the latter from the SW on 25 September. The high phosphate concentration might be related to the elevated level of pH in the dry season (Gao *et al.* 2012), as this promotes desorption of sedimentary inorganic phosphorus.

The **Iron** concentrations ranged from 13.0 to 1,380 mg/l. The highest value was reported from the WWE in the first January sampling. Iron concentrations differed significantly between the wet and dry seasons, with the higher levels occurring in the wet season.

As all the water in Nadosoito dam is derived from surface runoff, the iron concentration in its water is likely to increase during rainfall. This is due to the possible release of soluble iron to water from natural deposits in soil, leaching from underlying rocks and stones on the catchment. Iron is involved in phosphorus dynamics in fresh water; Fe (III) oxides and hydroxides readily adsorb and precipitate phosphate. This could explain the differences between phosphate concentrations in the wet and dry seasons. In aerobic conditions, interactions between colloidal organic material and iron decrease the extent of phosphate adsorption onto Fe-organic complexes and increase the availability of P to phytoplankton (Koenings & Hooper 1976). Whenever human activities, e.g. pastoralism and cultivation, disturb the balance of soils rich in iron, the inflow of iron into the water system is likely to be enhanced (Heikkinen 1990). This is because the loose soil particles are prone to erosion by the surface runoff and are subsequently washed out into the dam.

Phycocyanin pigment

In the wet season, the PC concentration varied from 38.1 to 495 μg/l. It was highest in January at the WWE and lowest in April at the SW. The mean PC concentrations recorded in the dry season were 94.8 and 104.0 μg/l at the WWE and SW, respectively; relatively much closer than in the wet season. The most likely time for a cyanobacteria bloom is after inflows deliver significant quantities of nutrients to the reservoir. The minimum concentration in the dry season was 19.9 and the maximum 175.7 μg/l. Since a PC concentration of 30 μg/L is reported as equivalent to WHO 'alert level 1' of 20,000 cyanobacterial cells/mL (Brient *et al.* 2008), this implies that the PC concentration in all but one sampling session in both seasons exceeded the WHO alert level. (In one case in the dry season the PC concentration was reported as 19.85 μg/l.) Without essential nutrients, principally nitrate and phosphate, algae will usually not reach bloom proportions and PC concentrations are expected to be low. Excessive nutrient input from land-based sources is a major cyanobacterial bloom promoting factor (WHO 2003).

Broadly, the phosphorus and nitrogen loads determine the rate and magnitude of cyanobacterial growth (PC concentration), which means that higher loads imply greater potential algal growth (Wetzel 2001). This was shown in this study when high PC concentrations in the wet season coincided with high nitrate concentrations. The phosphate trend opposed that of the PC concentration, being higher in the dry season than the wet. Medium- to long-term management measures for cyanobacterial control include identification of nutrient sources (phosphorus and nitrogen) and significant reduction of nutrient input, to reduce the proliferation of both cyanobacteria and other potentially harmful algae (WHO 2003). Carmichael (1994) compiled case studies on nausea, vomiting, diarrhoea, and fever,

Water Practice & Technology Vol 13 No 3
doi: 10.2166/wpt.2018.083

and eye, ear and throat infections after exposure to mass developments of cyanobacteria. Cases of deaths among cattle, sheep, dogs, horses and pigs after drinking water containing cyanobacteria were reported by Francis (1878).

Faecal coliforms

Faecal coliform forming unit (CFU) concentrations generally declined from wet to dry season (Figure 6), with mean values of 3,213 and 2,029 CFU/100 ml at the WWE and SW, respectively, during the wet season. The maximum value recorded in the wet season was 8,810 CFU/100 ml at the WWE, while the minimum was 760, also from the same location (Table 1). The maximum value was recorded at the beginning of the rainy season in January, and arose because of the additional contamination from the catchment brought in by the surface runoff associated with rainfall. The minimum dry season value of 30 CFU/100 ml was obtained at the WWE in September, on the last sampling run of the season, while the maximum value in the dry season – 710.5 CFU/100 ml – was obtained at the SW. All values from all sampling events exceeded the WHO guidelines and the TZS value of 0 CFU/100 ml (TZS 2003; WHO 2006). The contamination is related to the transport – by runoff, etc – of animal and human faecal matter to the dam, and direct defecation by livestock as they drink from the dam.

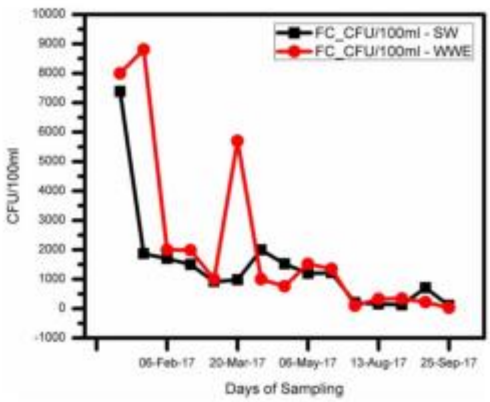


Figure 6 | FC concentration variation at WWE and SW from the wet to the dry season.

CONCLUDING REMARKS

The results obtained indicate high levels of turbidity (204 to 53,300 NTU) and high NO_3-N concentrations (0.6 to 1,715 mg-N/l), both of which require proper treatment to bring them to the TZS prescribed range (5 to 25 NTU and 10 to 75 mg NO_3^- N/l respectively).

The concentration of faecal coliforms (FCs) was highest in the wet season (8,810 CFU/100 ml) with a minimum value of 30 CFU/100 ml obtained in the dry season, both at the WWE. The highest and lowest FC concentrations at the SW were 7,380 and 110 CFU/100 ml respectively. All values in both seasons were above the TZS and WHO recommended values for drinking water (0 CFU/100 ml). The maximum value arose from the very high contaminant loading in the runoff into the dam during the wet season.

The observed PC concentration (19.9 to 495 μg/l) is a useful surrogate for the concentration of cyanobacteria present. The WHO guideline alert level for PC is 30 μg/l. The rather high concentrations of cyanobacteria, and hence PC, can probably be related to the incidence of diarrhoea among livestock and people, as well as livestock deaths reported in the area. The higher levels coincide with the wet season when there are significant runoff inflows that deliver large quantities of nutrients to the reservoir.

Nadosoito dam, like other earthen dams, has calm, nutrient-rich, warm and slow-flowing water, thus favouring the growth and proliferation of cyanobacteria. This is well depicted in the results. While there is little that can be done to control such proliferation in earthen dams, investigations into ways to reduce nutrient loading in the influent – e.g., runoff – could provide a solution that might reduce the associated human and livestock health impacts to a large extent.

The results obtained from this study will help to provide the necessary guidelines for the design and operation of the IPS constructed wetland system. The outcome will be to increase access to safe drinking water, thereby reducing the human health impacts associated with direct use of the dam water and reducing local medical costs.

As most of the parameters determined reported higher values at the WWE sampling point, it is recommended that water for treatment by the IPS constructed wetland system is drawn from the vicinity of sampling point SW.

ACKNOWLEDGEMENTS

This research was funded by British Gas (BG)/Shell to its completion. The Nelson Mandela African Institution of Science and Technology (NM-AIST) provided all necessary guidance, laboratory and other facilities, thus enabling accomplishment of this work. Finally, the support of the VLIR-OUS program in field and laboratory activities is acknowledged gratefully.

REFERENCES

APHA 2012 *Standard Methods for the Examination of Water and Wastewater 2012*. American Public Health Association (APHA)/American Water Works Association (AWWA)/Water Environment Federation (WEF), Washington, DC, USA.

Brient, L., Lengronne, M., Bertrand, E., Rolland, D., Sipel, A., Steinmann, D., Baudin, I., Legeas, M., Le Rouzic, B. & Bormans, M. 2008 A phycocyanin probe as a tool for monitoring cyanobacteria in freshwater bodies. *Journal of Environmental Monitoring* **10**(2), 248–255.

Carmichael, W. W. 1994 The toxins of cyanobacteria. *Scientific American* **270**(1), 78–86.

Chhatwal, R. J. 2011 *Environment Sciences- A Systematic Approach*, 2nd edn. UDH Publishers and Distributors (P) Ltd, Delhi, India, pp. 104–105.

Francis, G. 1878 Poisonous Australian lake. *Nature* **18**, 11–12.

Gao, Y., Cornwell, J. C., Stoecker, D. K. & Owens, M. S. 2012 Effects of cyanobacterial-driven pH increases on sediment nutrient fluxes and coupled nitrification-denitrification in a shallow fresh water estuary. *Biogeosciences* **9**(7), 2697–2710.

Heikkinen, K. 1990 Transport of organic and inorganic matter in river, brook and peat mining water in the drainage basin of the River Kiiminkijoki. *Aqua Fennica* **20**(2), 143–155.

Koenings, J. P. & Hooper, F. F. 1976 The influence of colloidal organic matter on iron and iron-phosphorus cycling in an acid bog lake. *Limnology and Oceanography* **21**(5), 684–696.

Kumar, V., Arya, S. & Dhaka, A. 2011 A study on physico-chemical charactersitics of Yamuna River around Hamirpur (UP), bundelkhand region central India. *International Multidisciplinary Research Journal* **1**(5), 14–16.

Msoffe, F. U., Kifugo, S. C., Said, M. Y., Neselle, M. O., Van Gardingen, P., Reid, R. S., Ogutu, J. O., Herero, M. & De Leeuw, J. 2011 Drivers and impacts of land-use change in the Maasai Steppe of northern Tanzania: an ecological, social and political analysis. *Journal of Land Use Science* **6**(4), pp. 261–281.

Orhon, D., Babuna, F. G. & Karahan, O. 2009 *Industrial Wastewater Treatment by Activated Sludge*. IWA Publishing, London, United Kingdom.

Senay, G. B., Shafique, N. A., Autrey, B. C., Fulk, F. & Cormier, S. M. 2002 The selection of narrow wavebands for optimizing water quality monitoring on the Great Miami River, Ohio using hyperspectral remote sensor data. *Journal of Spatial Hydrology* **1**(1), 1–22.

Tanzania Bureau of Standards 2005 National Env. Standards Compendium – TZS 789, 2005. http://www.tzdpg.or.tz/fileadmin/_migrated/content_uploads/National_Environmental_Standards_Compendium.pdf (accessed 9 May 2018).

Water Practice & Technology Vol 13 No 3
doi: 10.2166/wpt.2018.083

Trivedy, R. K. & Goel, P. K. 1984 *Chemical and Biological Methods for Water Pollution Studies*. Environmental Publications. Karad, India, pp. 211–215.

United Republic of Tanzania, National Bureau of Statistics 2012 *Census General Report*. http://www.tzdpg.or.tz/fileadmin/documents/dpg_internal/dpg_working_groups_clusters/cluster_2/water/WSDP/Background_information/2012_Census_General_Report.pdf (accessed 13 May 2018).

Vaishali, P. & Punita, P. 2013 Assessment of seasonal variation in water quality of River Mini, at Sindhrot, Vadodara. *International Journal of Environmental Sciences* **3**(5), 1424–1436.

Wetzel, R. G. 2001 *Limnology: Lake and River Ecosystems*, 3rd edn. Academic Press, New York, NY, USA.

WHO 1997 *Guidelines for Drinking-Water Quality, 2nd edn, Vol. 3. Surveillance and Control of Community Supplies 1997*. World Health Organization, Geneva, Switzerland.

WHO 2003 *Guidelines for Safe Recreational Water Environments: Coastal and Fresh Waters (Vol. 1) 2003*. World Health Organization, Geneva, Switzerland.

WHO 2006 *Guidelines for Drinking-Water Quality, 3rd edn. Vol. 1. First Addendum to Third Edition 2006*. World Health Organization, Geneva, Switzerland.

Poster Presentation

WATER QUALITY VARIATION AND POLLUTANTS TRANSFORMATION IN THE NADOSOITO DAM OF ARKATANI VILLAGE, MONDULI DISTRICT

Naziel Eliakimu, Karoli N. Njau, Revocatus L. Machunda
Department of Water, Environmental Science and Engineering, NM-AIST, Tanzania

Introduction

- Tanzania, especially in the semi-urban to rural areas people use the contaminated water from different sources (rivers, water, dams etc.) due to limited options (Mohamed *et al.*, 2016).
- This result in the global health burden associated with an estimated 4000–6000 children dying each day from diseases associated with lack of access to safe drinking water, inadequate sanitation and poor hygiene (UNICEF *et al.*, 2004)
- Arkatani village in Sepeko ward, Monduli District in Arusha region, being in a semi-arid area is faced with a water scarcity, and the available water (Nadosoito dam – a major source), is faced with the water quality issues which change through the year (Fig. 1)
- Reported animal mortality during certain periods of the year
- Could be associated with the presence of cyanobacteria in the water (SCA, 2010; Mbukwa *et al.*, 2013).
- This study intended to assess the seasonal dynamics of water quality and transformation of pollutants and microbial diversity in the dam

Objectives

Main Objective: To assess seasonal dynamics of water quality parameters and transformation of selected pollutants in Nadosoito dam

Specific Objectives:

1. To examine the seasonal dynamics of selected water quality parameters in the Nadosoito dam
2. To examine the seasonal diversity of selected microorganisms (Cyanobacteria, FC) and transformational products of selected pollutants in the Nadosoito dam

Significance of the research

1. Nadosoito Dam is the major source of water in Nadosoito and provides water for domestic and livestockAlso this study lays a basis for future studies.
2. Over 6000 inhabitants of Arkatani and surrounding villages depend on the dam for domestic supplies and watering animals (over 10 000 cattle, goats, sheep and donkeys), making it very important (Mtavangu, 2015)

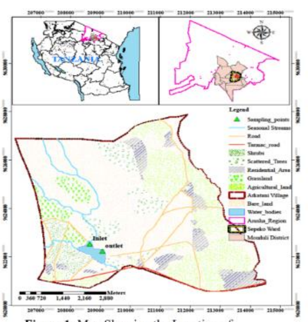


Figure 1: Map Showing the Location of Nadosoito Dam

- Nitrate, Nitrite, Ammonia, Iron, COD TSS - Spectrophotometer
- pH, Temp, DO, TDS, Turbidity – Field Measurements by a multi-parameter probe
- FC – Membrane Filtration Method
- Cyanobacteria/ Phycocyanin AquaFlour

APHA, 2012

Results and Discussion

(a) Water Quality Variation

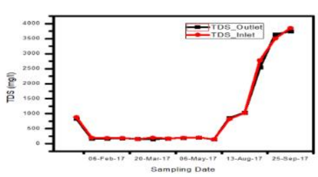


Fig. 2: TDS Variation at the Inlet and Outlet Sampling Site from Wet Season to Dry Season

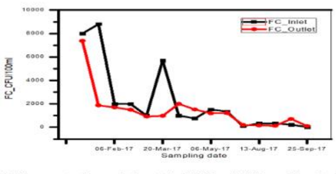


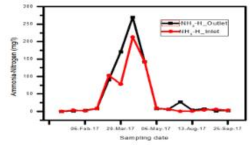
Fig. 3: FC concentration variation at the WWE and SW sampling site from wet season to dry season

- TDS varied from 141 to 882 mg/l, and from 822 to 3855 mg/l (inlet), in the wet and dry seasons respectively (Fig. 1)
- Concentrations below 1000 mg/l is usually acceptable for domestic use
- Turbidity at the dam ranged from 2920 to 53 300 NTU in wet season at the Inlet and 11 737 NTU at Outlet
- In the dry season, the turbidity ranged from 204 to 4330 NTU, at Inlet and 1613 NTU at the Outlet.
- Such values indicate the potential presence of harmful contaminants.
- WHO recommend <5 NTU as an acceptable turbidity range for drinking water (WHO, 2006)
- TZS for drinking water recommend a range of 5 to 25 NTU (TZS, 2003)
- In the context of the IPS, it was noted that pre-treatment of such high turbidity water will require more settling/sedimentation time

Fig. 4: Nadosoito Dam is wet season

Fig. 5. The Nadosoito dam in dry season

(b) Pollutant Transformation and Microbial diversity



$NH_4^+ \rightarrow NO_2^-$ ……………………………(i)

$NO_2^- \rightarrow NO_3^-$ ……………………………(ii)

$NH_4^+ \leftrightarrow NH_3 \leftrightarrow NO_2^- \leftrightarrow NO_3^-$ ……………(iii)

Fig. 6: Ammoniacal-Nitrogen Variation in the Wet Season

- Maximum (270 mg/l) occurred in April when we had long periods of rainfall in the area
- Nitrate (NO_3-N) was generally higher at Inlet than Outlet in samples taken in the wet season
- The difference in the two locations can explain the reduction of nitrate as water move down to the Spillway
- DO-Nitrate ($r= 0.998$, $p<0.01$) – high concentration of DO promoted the nitrification process by the microorganisms
- Nitrite was higher in dry season than in wet season
- Statistical analysis showed a negative correlation btn Nitrite and DO indicating the denitrification
- 30 µg/L is equivalent to WHO "alert level " of 20 000 cyanobacterial cells/mL (Brient *et al.*, 2008)
- All but one sampling session (19.9µg/l) reported the values above the standard
- Higher conc in the wet that in the dry
- PC-Phosphate ($r= 0.727$, $p= 0.017$) – the increase of phosphate in water favored the growth of cyanobacteria in water (Hoyer and Jones, 1983)
- Faecal coliform concentrations generally declined from wet to dry season (Fig. 3)
- All values from all sampling events exceeded the WHO guidelines and the TZS value of 0[zero] CFU/100ml (TZS, 2003; WHO, 2006)

(c) Conclusion

- All the values for PC but one were above the WHO alert level of 30µg/l
- The reasonably higher conc can be related to the incidence of diarrhoea among livestock and people, as well as livestock mortality in the area
- Looking on the trends, there is a variation on the major parameters with changes on the seasons
- Statistical analysis of the data revealed the transformation of pollutants (e.g. nitrate and phosphate) with significant changes in the physical parameters
- PC and FC were found to be moderated by physical water parameters including Temperature and pH
- The results obtained from this study help to provide the necessary guidelines for the operation of the IPS-constructed wetland system
- Further study to determine the species composition of the cyanobacteria in the dam
- Water for treatment by the IPS-constructed wetland system is drawn from the vicinity of the Outlet sampling point

Selected references

- APHA(Eds)(2012). *Standard Methods for the Examination of Water and Wastewater*, American Public Health Association (APHA)/American Water Works Association (AWWA)/Water Environment Federation (WEF), Washington DC, USA.
- Brient, L., Lengronne, M., Bertrand, E., Rolland, D., Sipel, A., Steinmann, D., Baudin, I., Legeas, M., Le Rouzic, B. and Bormans, M. (2008).A phycocyanin probe as a tool for monitoring cyanobacteria in freshwater bodies. *Journal of Environmental Monitoring*, **10**(2), 248-255.
- Hoyer, M. V. and Jones, J. R. (1983). Factors affecting the relation between phosphorus and chlorophyll a in midwestern reservoirs. *Canadian Journal of Fisheries and Aquatic Sciences*. **40**(2), 192-199.
- Mtavangu, S. (2015). Intergrating constructed wetland technology with sand filter for treatment of community domestic water in rural Tanzania. Unpublished Dissertation for Award of Masters' Degree at NM-AIST. Arusha, Tanzania, pp. 7 – 30.
- Mbukwa, E. A., Boussiba, S., Wepener, V., Leu, S., Yuval, K., Msagati, T. A. and Mamba, B. B. (2013). Potential use of dissolved cyanobacterial DNA for monitoring toxic Microcystis cyanobacteria in filtered water. *Physics and Chemistry of the Earth, Parts A/B/C*. **66**, 167-172.
- Mohamed, H., Clasen, T., Njee, R. M., Malebo, H. M., Mbuligwe, S. and Brown, J. (2016). Microbiological effectiveness of household water treatment technologies under field use conditions in rural Tanzania. *Tropical Medicine & International Health*. **21**(1), 33-40.
- Tanzania Bureau of Standards. (2003). National Env. Standards Compendium - TZS 789 :2003. http://www.tzdpg.or.tz/fileadmin/_migrated/content_uploads/National_Environmental_Standards_Compendium.pdf . Accessed on April 24, 2018.
- UNICEF and WHO (2004). Meeting the Drinking Water and Sanitation Target: A Mid-Term Assessment of Progress. UNICEF/WHO, Geneva, Switzerland.
- www.waternsw.com.au/__data/assets/pdf_file/0020/60149/SCA-Cyanobacteria-Risk-Profile-2010.pdf . Accessed on April 20, 2018).