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FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

DEPARTMENT OF CROP SCIENCE

ASSESSMENT OF IRRIGATION WATER QUALITY ON SURFACE WATER SOURCES



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DECLARATION

I, Tatenda Patience Matanda (B222316B) do hereby declare to the Senate of Bindura University of Science Education that this research is a result of my original work. It is bring submitted for the fulfilment of the Bachelor of Agriculture Honors Degree in (Crop Science). The findings had neither been submitted nor being concurrently submitted in any other institutions.

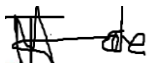
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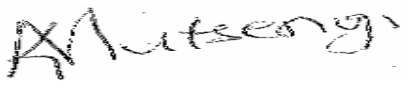
Date

I have supervised the above research project and I am convinced that the research project can be submitted.

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Signature 

Date 25/06/26

Chairperson Mr K. Mutsengi  02/09/26

DEDICATION

This project is dedicated to my parents.

ACKNOWLEDGMENTS

Firstly, I want to thank God for making this project success. My special gratitude goes to my family for their love, financial support and prayers throughout my studies. My special support also goes to my supervisor Dr T. Goche for his support. My deepest gratitude goes to Mrs P. Matsika for her guidance, patience and continuous support throughout this study. Special appreciation goes to Mr. Mutero my field technician and Mr. E. Mukusa, my laboratory technician for all his technical assistance, laboratory support during the experimental phase of my research. I also acknowledge my friends Artwel, Panashe, Prince and Melody for the encouragements and motivation during the course of this project. My last smile and appreciation goes to Bindura University of Science Education, especially to the Department of Crop Science and everyone who contributed.

ABSTRACT

The quality of irrigation water plays a vital role in determining the health status of soil and crop productivity. This study evaluates the quality of water drawn from SOS dam at Bindura University of Science education (BUSE) farm based on the physicochemical and biological parameters. Four sampling times were conducted from April to May 2026. Ten sampling sites (S1-S10) were set at different location in the dam and samples were collected at weekly basis. Parameters tested include temperature, pH, electrical conductivity (EC) and total coliform bacteria. Physicochemical parameters were analyzed using portable multi-parameter meter while biological parameter were analyzed using the pour plate technique on MacConkey agar. The data was analyzed by Analysis of Variance (ANOVA) using GenStat software and treatment means were separated using Least Significant Difference (LSD) test at 5% significant level. The results indicated that the temperature varied between 23.53˚C and 26.10˚C with relative constancy through time of the experiment . There was a significant difference ($p \leq 0.05$) in pH and EC among the sampling point, however, significant difference in temperature was noticed only during the late stage of sampling periods. The mean value of pH varied from 6.50 to 9.23 while mean value of EC was 213.3 to 316.3µS/cm indicating presence of low to moderate salinity danger. No significant difference ($p>0.05$) was seen in total coliform count among the sampling points. This implied uniformity in microbial contamination in the dam. In general, the physicochemical parameters analyzed were within acceptable range for irrigation water. However, some of the sampling points had slightly higher pH values. The conclusion reached by the study was that the SOS Dam water is suitable for irrigation and gardening purposes. Nevertheless, regular testing of the quality of the water should be done for any change that may occur due to the above stated reasons.

Key words: Irrigation water quality, surface water, electrical conductivity, pH, total coliform bacteria and physiochemical parameters.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Full Form
ANOVA	Analysis of Variance
BUSE	Bindura University of Science Education
CFU	Colony Forming Units
CRD	Completely Randomised Design
CV	Coefficient of Variation
EC	Electrical Conductivity
FAO	Food and Agriculture Organization
LSD	Least Significant Difference
ml	Millilitre
mm	Millimetre
NaOH	Sodium Hydroxide
SAR	Sodium Adsorption Ratio
SED	Standard Error of Difference
TDS	Total Dissolved Solids
WHO	World Health Organization
µS/cm	Microsiemens per centimetre

°C	Degrees Celsius
%	Percentage

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Irrigation is the most reasons for producing food all over the world as a stabilization tool since it acts like a buffer which makes the production of food independent of rain. FAO (2020) indicates that irrigated agriculture provides approximately 40% of the global food production even though the area cultivated for irrigation is just 20% of the cultivable land in the world. According to Domènech, (2015), irrigation could help in improving food security through the provision of food products in terms of availability and access. Irrigation is an insurance tool that protects farmers from total crop failure due to unpredictable rain. According to Worqlul *et al*., (2018), the chance of food security is 32 times higher among irrigators than non-irrigators.

Water quality changes based on where contaminations come from, what season it is and the geology of the riverbed (Ubah *et a*l., 2021). In semi-arid regions like Bindura, irrigation serves as an important too that compensates for inadequate rainfall. According to Behzad *et al.,* (2009), small-scale irrigation is an important mechanism to mitigate risk associated to rainfall variability in subsistence farming. The contribution of small holder irrigation has been giving rise to economic growth (Mupaso *et al*., 2024).

When the concern is about water quantity, quality is just as important for sustainability in the long run. Poor quality of irrigation water creates dangers such as salinity, sodicity, ion toxicity and pH imbalance affecting the soil and water itself (Zaman *et al*., 2018). Salinity refers to total accumulation of salts that are soluble in water within soil profile (Choudhary & Kharche, 2018). Effect of salinity is seen on soil because during evaporation, these salts are

left and become accumulated in the root zone (Yadav *et al*., 2011). High salinity affects the soil in such way that the water pulling effect of salt in the soil osmotic is reduced, thereby making it hard for plants to absorb water (Shahid *et al*., 2026). Water used for irrigation with a EC value below 0.7 ds/m creates no restriction whereas EC exceedin 3.0 ds/m greatly restricts the growth. Increased sodium content (Na+) relative to calcium (Ca2+) and magnesium (Mg2+) results in dispersal of clay particles due to sodium adsorption ratio (Zaman *et al*., 2018).

According to Kalaivanan and Ganeshamurthy., (2016), toxicity happens when specific ions are absorbed by the plant and accumulate to damaging levels in the leaves. The toxins include chloride, sodium and boron. This toxins cause leaf burn, necrosis and yellowish o plants (Setia *et al*., 2012). According to Ayers & D.W. Westcot, (1985), pH of water directly influence whether essential minerals remain dissolved and available for plant uptake. High pH, micronutrients like iron (Fe), manganese (Mn), zinc (Zn) and copper often oxidize leading to deficiency symptoms. Low pH can increase the solubility of aluminum (Al), and manganese (Mn) to toxic levels which can affect the crop growth (Muhammad *et al*., 2018).

The increasing frequency of climate induced drought has made rain-fed agriculture highly unreliable, forcing a strategic shift towards small-holders irrigation scheme as a primary adaptation measure (Tefera *et al*., 2025). While the expansion of irrigation is essential for year-round crop production and its sustainability is highly depended on water quality for irrigation. Research indicate that increasing salinity and sodium levels in irrigation water significantly increase soil pH and reduce soil aggregate stability leading to poor soil physical conditions (Wei *et al*., 2022). Khani *et al.*, (2013) reported that saline water has been shown to reduce nitrogen and phosphorus availability in soils after irrigation cycles, which negatively impact crop productivity.

In the context of Bindura, BUSE farm serves as a vital hub for both institutional agricultural production and model for surrounding small holder farmers. The farm and neighbouring smallholder small-scale irrigator primarily draw water from the Mazowe River and its tributaries, as well as local groundwater sources. The Mazowe River catchment is an area of intense human activities, characterized by a complex interplay of large-scale commercial farming, small-scale horticulture and significant artisanal and small-scale gold mining (Charema, 2024).

These sources of water have recently become a matter of concern due to chemical and physical pollution in the area (Akhtar *et al*., 2021). Mining operations carried out in the Mazowe River area could result in contamination of the water bodies with mercury and cyanide which may be harmful when used to irrigate maize and vegetables (Dube, 2024). Moreover, runoff from farmlands brings high concentrations of nitrogen and phosphorus to the reservoirs and rivers causing their eutrophication (Wurtsbaugh *et al*., 2019).

However, despite obvious problems, there is no up-to-date research of the water quality in this particular farm and its influence on the smallholders in the vicinity. Smallholder farmers lack technical resources to detect contaminants in water.

1.2 Problem statement

Bindura farm highly depends on irrigation to supplement rainfall. However, the quality of irrigation water used is often unknown and rarely tasted. Poor irrigation water quality, particularly high sodium levels and unfavourable pH may lead to soil structure deterioration, reduced infiltration and decreased nutrient availability. This can result in reduced crop growth and long-term soil productivity decline. Therefore, water quality needs to be assessed and determine its effects on soil structure and nutrient availability in smallholder farms.

Small-holder farmers in Bindura increasingly depend on irrigation to sustain agricultural production due to the variability and unreliability of rainfall. Irrigation is very important in improving food security and stabilizing crop yields, particularly in arid regions. However, the effectiveness of irrigation is not determined solely by the availability of water but also by quality. Irrigation water quality is a key factor influencing soil health, crop productivity and long-term sustainability (Bilali & Taleb, 2020). The accessibility and storage of dam water make it mostly used by small-holder farmers. The quality of dam water however is highly dynamic, influenced by several environmental factors such as evaporation, surface runoff and accumulation of dissolved salts. During dry periods, evaporation can increase salt concentration in stored water while runoff can introduce nutrients and other chemicals into the dam Ayers and Westcot, (1994). This process may result in deterioration of water quality over time making it not suitable for irrigation.

Use of poor-quality irrigation water is a serious consequence on soil and crop performance. High level of dissolved salts in irrigation lead to soil salinization which reduce osmotic potential of soil water and limit plant water uptake, (Machando *et al*., 2017). Excess sodium in irrigation can result in soil sodicity, causing dispersion of soil particles , reduced infiltration and poor soil structure, (Smith *et al*., 2014).

Despite the importance of irrigation water quality, many smallholder farmers in Bindura rely on dam water without prior assessment of its suitability. There is a limited monitoring of water quality parameters such as electrical conductivity, pH, temperature and coliforms. Existing studies have largely focused on general irrigation practices paying no attention to temporal variations in water quality within specific water sources. This lack of information creates a significant knowledge gap as farmers may unknowingly use water that poses risk to soil health and crop production. In addition, absence of localized data on irrigation water quality makes it difficult for agricultural extension service to provide appropriate

recommendations to farmers. Small holder farmers highly depend on irrigation to supplement rainfall. However, the quality of irrigation water used is often unknown and rarely tested. Poor irrigation water quality, particularly high sodium levels and unfavourable pH may lead to soil structure deterioration, reduced infiltration and decreased nutrient availability. This can result in reduced crop growth and long-term soil productivity decline. Therefore, this study seeks to assess the physicochemical and biological quality of dam water in order to determine its suitability for irrigation.

1.3 Justification of the study

For Bindura area, BUSE farm is an important centre not only in terms of institutional agriculture but also as an example for the small holder farms around. The farm and nearby smallholder small-scale irrigators mainly rely on water from the Mazowe River and its tributaries, as well as ground water. The Mazowe River catchment zone has a very strong interaction with humans with a number of intensive economic activities including large-scale commercial agriculture, horticulture on smaller scale as well as artisanal and small-scale gold mining.

There have been serious concerns about the quality of water sources through recent research in the area. There has been heavy metal pollution of water due to mining activities carried out in Mazowe river that may lead to pollution with mercury and cyanide which may cause health hazards when used for irrigation of maize and vegetables. Irrigation on farmland results in increased levels of nitrogen and phosphorous in local dams and rivers.

Despite these evident risks, there is a lack of localized up-to-date assessment specifically focusing on BUSE farm and its impact on the surrounding smallholder community. Smallholder farmers often lack the technical capacity to test for invisible hazards like heavy metals making them more vulnerable to long-term soil productivity.

The research will help farmers to identify suitable irrigation water sources. It also helps farmers to prevent soil degradation caused by saline and sodic soils. It also improves irrigation management practices, support sustainable crop production and provides local data for Bindura smallholder farmers.

1.4 Objectives

1.4.1 Main objective

To assess the suitability of water from SOS dam for irrigation using selected physicochemical and biological parameters for the surface water source at the Bindura University of Science Education farm for gardening purposes.

1.4.2 Specific objectives

1. To determine the physicochemical quality of irrigation water by measuring pH , temperature and electrical conductivity (EC) of SOS Dam.
2. To determine the microbiological quality of irrigation water by assessing the total coliform count water from SOS Dam.
3. To evaluate the suitability of SOS Dam water for irrigation based on recommended irrigation water quality standards

1.5 Hypotheses.

1. H_O: There is no significant difference in the physicochemical quality (pH , temperature and electrical conductivity of the irrigation water from the recommended standards for irrigation use.
2. Ho: There is no significant coliform contamination in the irrigation water, indicating that the water is microbiologically suitable for irrigation use.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Water quality is an important aspect in agricultural productivity particularly under irrigation setup. According to FAO (2020), the suitability of irrigation water depends on its physiochemical and biological properties, which directly influence soil structure, nutrient availability and plant growth. Poor quality irrigation can cause soil degradation processes such as salinization, sodicity and toxicity which in turn reducing yield and long-term land productivity. While irrigation systems can effectively increase crop yields, they also show risks if water management is not monitored, as noted by Domènech (2015). Water contaminated with excess salts or pathogenic microorganisms may negatively affect agricultural productivity and may also cause health risk through contamination of crops and soils. Therefore, regular monitoring of water quality is important for ensuring safe and good agricultural practices.

2.2 Irrigation water quality concept

Suitability water for crop production without negatively affect soil characteristics, plant growth or the environment is referred to as irrigation water quality. The Food and Agriculture Organization (2020), state that concentration of dissolved salts, sodium hazard and specific ion toxicity determines water quality. Specifically, concentration and composition of soluble salt in the water determines whether its suitable for human, animals and irrigation (Husman,2017). Therefore, water quality becomes a major concern when salinity buildup is likely in an irrigated farming area (Yoshikawa *et al*., 2014). Soil salinity, sodicity and nutrient imbalances brought on the poor-quality irrigation water can lower

agricultural productivity. According to Universitas & Nitriae,(2021), the chemical and physical characteristics of soil, including infiltration rate, soil structure and nutrient availability are influenced by the quality of irrigation water (Daba & Qureshi, 2021). According to Ayers and Westcot (1985), water with a high salt content can build up in the root zone, stressing plants osmotically and decreasing their ability to absorb water. According to Mateo Sagasta *et al*., (2017), agriculture is both victim and contributor to water pollution due to the release of sediments, nutrients, pesticides and microbial contaminants into water bodies.

2.3 Sources of irrigation water

Surface and ground water sources like rivers, dams, lakes, boreholes and wells are frequently used to provide irrigation water (Yoshikawa *et al*., 2014). Smallholder farmers frequently use surface water sources such as dams, because of their accessibility and storage capacity. However, rainfall, runoff, evaporation and nearby land use can all affect the quality of dam water. (Al-Omran *et al*., 2010) suggested that over time, sediments and dissolved salts may build up in dam water. Evaporation raises the concentration of salt in stored water during dry spell, making it less suitable for irrigation. Furthermore, agriculture runoff can change the chemistry of water in dams by introducing salts and nutrients (Sheoran *et al*., 2021). Therefore, it is crucial to monitor dame water quality in order to guarantee sustainable irrigation methods.

2.4 Irrigation water quality parameters

Different methods have been used for evaluation of water quality. The United States salinity laboratory stuff consider salinity and sodicity hazards together based upon electrical conductivity (EC) and sodium adsorption ratio to assess irrigation water quality, however in order to improve applicability of these systems, it is good to incorporate more parameters

(Abdi *et al*., 2015). These include pH, electrical conductivity (EC), total dissolved solids (TDS), sodium, calcium, magnesium, and chloride and bicarbonate ions. Measurement of physical-chemical parameters is typically time consuming, cost-intensive and depend on special instruments (Block *et al*., 2019). Also, physical-chemical parameters can only show water quality at the moment of measurement and can change rapidly over time in response to numerous conditions (Alavaisha *et al*., 2019).

The suitability of irrigation water depends on salinity levels, sodium concentration, pH, microbial contamination, toxic elements and suspended materials (Bortolini, Maucieri, & Borin, 2018). However, salinity is considered the most significant challenge affecting irrigated agriculture. High salinity levels reduce the ability of plants absorption due to osmotic stress. Also, irrigation water contaminated with pathogenic microorganism led to the contamination of fresh produce hence affecting public health (Steele & Odumeru.,2004). Several foodborne disease outbreaks have been associated with contaminated irrigation water used in vegetable production system and horticulture.

Total amount of salts in water is represented by all dissolved solids. Salinity issues are linked to high TDS values (Adjovu *et al* 2023). The concentration of sodium is crucial because too much sodium can disperse soil particles, replacing calcium and magnesium in soil. Soil permeability and structure are preserved with the aid of calcium and magnesium. In Bicarbonates affect carbonate hazard and can cause calcium and magnesium to precipitate, which increases the effects of sodium, (Khani *et al*., 2021).

2.4.1 pH and irrigation water quality

pH indicates how acidic or alkaline water is (Omer,2019). pH scale extends from 0 to 14 and the values below 7 indicate acidity and those above 7 indicate alkalinity. According to FAO, (2020), the pH of water used for irrigation has an effect on nutrient availability, microbial

activity and chemical reactions in the soil. Water with extreme low or high pH has the potential to negatively affect plant growth and reduce nutrient uptake. According to Ayers and Westcot (1985), irrigation water having a pH values ranging between 6.5 and 8.4 is considered suitable for agricultural use. Acidic water may increase the solubility of toxic metals, while alkaline water reduces the availability of essential nutrients such as phosphorous, iron and zinc. Changes in pH also affect soil structure (Hussain *et al*., 2026). The acidity or alkalinity of irrigation water is indicated by its pH. Water with a pH of 6.5 to 8.4 is deemed appropriate for irrigation. Soil structure issues and nutrient deficiency can result from highly alkaline water. Several studies have reported variation in irrigation water pH due to geological condition, industrial pollution and agricultural runoff. Ph variations in irrigation water sources were influenced by surrounding land use activities (Ahmad *et al* 2021).

2.4.2 Electrical conductivity and irrigation water quality.

Electrical conductivity (EC) serves as a measure of waters ability to conduct electrical current and it is extensively applied to determine the level of dissolved salts (Rusydi, 2018). Electrical conductivity is most important indicators of salinity in water. High EC values indicate high concentration of dissolved ions including sodium, calcium, magnesium and chloride (Boci *et al*., 2024). Excessive salinity in irrigation water led to reduced plant water uptake, decrease crop yield and contribute to soil salinization. According to FAO (2020), water EC values below 0.7 ds/m generally pose low risk of salinity, while values above 3 ds/m create severe salinity problems. Plant water uptake is decreased by high EC values, which are indicative of high salt concentration(Kadyampakeni *et al*., 2018).

2.4.3 Salinity Hazard in irrigation water

Salinity refers to presents of soluble salts in irrigation water (Zaman *et al*., 2018). Plants find it more difficult to absorb moisture when soil water has a low osmotic potential due to high salinity. Water with an electrical conductivity of more than 3 dS/m is deemed extremely saline and inappropriate for many crops (Ubah *et al*., 2021). By decreasing seed germination, restricting nutrient uptake and causing leaf burn, salinity has an impact on plant growth. Particularly affected are crops that are sensitive to salt, like carrots and beans. Long-term use of saline water causes salts to build up in the soil, which lowers productivity. According to studies, irrigated agriculture frequently experiences salinity issues when evaporation surpasses rainfall (Velasco-muñoz *et al*., 2019). Salinity affects plants by increasing osmotic pressure around roots, making it difficult for plants to absorb water (Balasubramaniam *et al*., 2023). Sensitive crops such as bean, carrot and onion are more vulnerable to salinity stress compared to tolerant crops like barley and cotton. Increasing evaporation rates due to climate change contributed to rising salinity levels in many irrigations water source.

2.4.4 Temperature and water quality

Temperature is important physical parameter as it influences chemical, biological and ecological process in water bodies. Water temperature affects dissolved oxygen concentration, microbial activity and chemical reactions rates (Rajendiran *et al*., 2023). High water temperature promotes the growth of microorganism including coliform bacteria (Shaheduzzaman *et al*., 2016). Temperature also affects aquatic ecosystem and also influences irrigation efficiency. Surface water bodies such as dams are particularly affected by atmospheric temperature, solar radiation and climatic conditions (de Souza Dias *et al*., 2018). According to World Health Organization, elevated temperature may increase microbial activity and contribute to deterioration of water quality. Seasonal variation often influences water temperature in dams. Research conducted by Dalu *et al*., (2018) in

Zimbabwe reported that water temperature variations in reservoirs were associated with climatic conditions and anthropogenic activities around water sources.

2.4.5 Coliform Bacteria and Irrigation Water Quality

Coliform bacteria are commonly used as indicators of faecal contamination in water (Khan & Gupta, 2020). Their presents suggest contamination by human or animal waste and possible presents of pathogenic microorganism.

Irrigation water contaminated with faecal microorganism may contaminate vegetables and fruits especially crops consumed raw such as lettuce, tomatoes and cabbage (Uyttendaele *et al*., 2015). Contaminated irrigation water has been linked to outbreaks of diseases caused by pathogens such as Escherichia coli, Salmonella and Shingella (Akinde *et al*., 2016). According to Steele and Odumeru (2022), microbial contamination of irrigation water remains a major food safety concern worldwide. Sources of microbial contamination include sewage discharge livestock activities, runoff and poor sanitation practices.Gelting *et al*., (2015) reported 2 nationwide disease out-breaks in the United States that were directly linked to consumption of vegetables contaminated with pathogens from irrigation water.

Coliform analysis is widely used because it provides a relatively simple and cost-effective method of assessing microbial water quality. Culture media such a MacConkey agar are commonly used for isolation and enumeration of coliform bacteria.

2.5 Sodium hazard and sodicity

Sodium hazard refers to the risk associated with high sodium concentration relative to calcium and magnesium (Alobaidy *et al*., 2010). The Sodium Adsorption Ratio (SAR) is used to evaluate sodium hazards. High SAR values indicate potential soil sodicity. Sodic soils have poor structure, low permeability and reduced infiltration (Gangwar *et al*., 2019). This result in waterlogging and poor aeration, which negatively affect root development. High

sodium level also causes dispersion of clay particles, leading to surface crusting and reduced seedling emergence. Research conducted by Demo *et al* (2025) indicates that long-term irrigation with sodic water reduces soil productivity and increase erosion risk.

2.6 Effects of poor irrigation water on soil

Low quality water can result in different problems like toxicity for crops, damage to soil quality, diffusion of parasites and drawbacks in irrigation systems (Qadir *et al*., 2013). The physical and chemical properties greatly impacted with poor irrigation water quality (Bortolini *et al*., 2018). Physical and chemical properties are impacted with poor irrigation water quality. Reduced soil fertility results from addition of salts in the root zone caused with high salinity. Reduced infiltration and poor drainage are the results of soil particle dispersion caused by sodicity. Excess bicarbonate cause calcium and magnesium to precipitate, which increase the risk of sodium poisoning. Nutrient cycling and soil microbial activity are also impacted by poor quality irrigation (Kadyampakeni *et al*., 2018)

2.7 Effects on crop production

Salinity problem happens when too much salt builds up in the soil and irrigation water; this makes it harder for plant to absorb water which then reduce crop yield. The ion toxicity problem creates excess nutrients which lower the quality and thus the marketability of produce (Ubah *et al*., 2021).

The good irrigation water is essential for healthy crop growth and better farm yields (Fahad *et al*., 2018). Osmotic stress brought about by high levels of salinity hinders plant growth. Sodium toxicity can lead to reduction of photosynthesis and leaves burning. Chloride toxicity impacts crops such as citrus fruits and beans. The nutrient imbalance caused by the poor quality of irrigation water can affect plant metabolism. Research suggests that the consistent application of saline water leads to reduced yields (Babu, 2020). The impact of saline water

on salt sensitive plants such as maize is greater than on salt tolerant ones such as barley and cotton. The major disadvantage of high EC water on the outcome of crops is the lack of performance of plants.

2.8 Irrigation water quality in smallholder systems

In irrigation practice, smallholders use dams located close to their fields. Inappropriate water use is more likely to be applied by these farmers since they do not conduct water tests regularly. Due to absence of monitoring, salinity and sodicity remain significant issues in smallholder irrigation in Southern Africa (Chemura *et al*., 2014).

Salinity and sodicity can depend on such factors as rainfall, evaporation, and agricultural practices that influence the dam water. Evaluations are necessary due to seasonality that influences salt concentration. Problems like salinity and sodicity have been found to occur in many places and are considered major ones of irrigated agriculture (Bilali & Taleb, 2020). More than 900 million hectares worldwide are affected by salinity and sodicity, representing over 6% of global agricultural land and approximately one-fifth of irrigated land (Chemura *et al*., 2014). Soils classification as saline or sodic is based on the concentration of soluble salts measured from the electrical conductivity (EC) of saturated soil extracts (Shahid *et al*., 2018).

2.9 Irrigation Water Quality Standards

Irrigation water quality standards give the guidelines used to check if water is safe to use for farming. FAO and WHO provide recommended limits for various irrigation water quality parameters.

Table 2.9: Irrigation Water Quality Standards

Parameter	Recommended range

pH	6.5 – 8.4
EC	Less than 0.7 ds/m (low salinity risk9)
Temperature	Variable
Coliform count	Should be minimal

Water exceeding recommended standards may require treatments or management before use in irrigation.

CHAPTER 3

METHODOLOGY

3.1 Study area description

The project was done at Bindura University of Science Education (BUSE) on a farm that is located close to Shamva Agricultural College in the Mashonaland central region. It falls under the natural region IIa, which receives an annual rainfall of between 700 to 1050 mm. The geographic location of the farm is 17 14` 29'' S, 31 03` 54''E at an altitude of 1400 meters above sea level and the average temperature of region is 20 degrees centigrade and soil type is sandy-loam. The dam can serve different functions such as drinking water for domestic use, irrigation, livestock watering, fisheries and recreation.

3.2 Research Design

An experimental research approach was adopted, which involved gathering water samples and conducting laboratory analyses of specific water quality indicators. The research focused on assessing selected physiochemical and biological characteristics of dam water in order to determine its suitability for irrigation purpose. Four sampling rounds were conducted to assess temporal variations in irrigation water quality. A random sampling technique was used

to minimize selection bias and ensure that the collected water sample were representative of the dam. The shoreline of the dam was first divided into ten accessible sampling locations. Each location was assigned a unique identification (S1-S10). The sampling points were then selected randomly by drawing the numbers' locations without preference. These selected locations served as the experimental units throughout the study. At each sampling point, three replicates water samples were collected during each sampling round. Sampling was conducted once per week for four consecutive weeks, giving a total of 120 samples (10 sampling points × 3 replicates × 4 sampling rounds). The samples were analyzed for selected physicochemical and biological parameters and compared with water quality standards. Ten sampling points were selected across the dam and treated as experimental units. Three replicate samples were collected from each sampling point during each week to improve the accuracy of the results.

Table 3.2: Sampling schedule

Week	Sampling round	Date	Activity
Week 1	1	Mid-April	Water sampling
Week 2	2	Late-April	Water sampling
Week 3	3	Early- May	Water sampling
Week 4	4	Mid- May	Water sampling

3.3 Sampling procedure

Samples were selected from a single dam to account for spatial variation. Ten sampling points were initially selected across SOS Dam and permanently marked for the duration of the study using visible landmarks surrounding the Dam. The landmarks served as the reference points to enable repeated sampling at the same location throughout the study

period. Samples were collected at depth of approximately 10-25 cm below to avoid surface contamination. At each sampling point, three replicate samples were collected and properly labelled according to the sampling point and sampling week. After collection, water bottle was placed in cooler box for transportation to laboratory. Care was taken during handling and transportation to maintain sample integrity and contamination risk. The sampling points were labelled S1-S10 for easy identification and data recording purpose. The samples were collected in dam on different points to account for spatial variation within the dam.

3.4 Sample collection

Water samples were collected using clean 500 ml plastic bottle. Before sampling, each bottle was washed with water from the dam to avoid contamination. Water samples were collected done below the surface to prevent flowing materials. Each sample were labeled with the place from where the samples were collected and their date and water sources. After collecting the samples, they were filled in the bottles with water and stored in a refrigerator at around 4 degrees centigrade for 72 hours and then taken to the laboratory for testing the ionic balance. The tests in the laboratory were carried out quickly to prevent any alteration in the quality of water.

3.5 Parameters measured

The study assessed both physicochemical and biological parameters that determine irrigation water quality.

3.6 Determining of physiochemical parameters

The physiochemical parameters of water namely pH, EC and temperature were measured using a portable multiple meter. Prior to use, the machine was calibrated according to the manufactures instructions to ensure accurate measurement. Water was collected from every sampling point and tested. The probe of the multi-parameter was immersed in the water

samples and left until the readings stabilize before measurements were recorded. Measurement for pH, temperature and EC were taken for all samples collected from ten points during each sampling week. Three replicates were obtained for each sampling point and the recorded values were used for subsequent statistical analysis.

3.7 Determining of total coliform count

3.7.1 Preparation of ringer solution

Ringer solution was made using required amount of sodium chloride, potassium chloride, calcium chloride and sodium bicarbonate in water. The solution was mixed and autoclaved at 121˚C for 15 minutes before use in serial dilution of water samples.

3.7.2 Preparation of culture media

MacConkey agar was prepared in the laboratory following the manufacturer's instructions. The required amount of dehydrated MacConkey agar powder was accurately measured using an analytical balance and dissolved in 250ml of distilled water and sterilized before use. The prepared culture medium was autoclaved. After sterilize the culture media allowed to cool and poured into sterile petri dishes for the enumeration of total coliform bacteria in the water samples.

3.7.3 Sterilization of equipment

The glassware and equipment used during microbiology analysis were thoroughly cleaned and sterilized before the use to prevent contamination. Petri dishes, conical flask, pipettes, dilution bottles and other laboratory were washed with detergent and rinsed with distilled water. The cleaned materials were put in an autoclave at 121˚C and 15 psi pressure for 15 minutes. The materials were cooled before use and handled aseptically throughout the analysis.

3.7.4. Determination of total coliform.

Total coliform level was assessed using pour plate technique, samples from each sampling points transported to the laboratory in a cooler box and analysed under aseptic conditions. Ten-fold serial dilution were made with sterile Ringer solution. Briefly, 2 ml of sample transferred into 8 mL of sterile Ringer solution to obtain the first dilution and subsequent dilutions were prepared in the same way until the target dilution achieved. A 1 ml aliquot of the appropriate dilution was pipetted aseptically changed into sterile Petri dishes. Molten MacConkey agar was allowed to cool to and added into each Petri dish and mixed gently, to ensure uniform distribution of microorganisms throughout. The agar was left to solidify at room temperature.

Inoculated plates were incubated at 37°C for 24 hours. After incubation, colonies that appeared were counted with a colony counter. Only plates with clear, countable colonies were used. CFU/ml was then calculated following standard microbiological methods. Most plates had between 10 and 120 colonies. CFU/ml was determined using the formula.

$$\text{CFU/ml} = \frac{number\ of\ colonies\ \times Dilution\ factor}{volume\ plated\ (ml)}$$

Three replicate samples were analysed for each sampling point, and the resulting CFU/ml values were recorded and used to assess the microbiological quantity of water from SOS dam. Total coliforms were used as indicator organisms to assess the microbiological quality of water. Their presence provides an indication of possible contamination from environmental and anthropogenic sources.

3.8 Aseptic Techniques

Aseptic techniques were noted through the entire process of microbiology testing in order to reduce contamination. The preparation of media, as well as the dilutions and counts,

was carried out in a sterile environment. All processes of sampling were done in sterilized equipment.

3.8.1 Pour plate method

Pour plate technique was put in the focusing of coliform bacteria present in water samples collected. The dilutions water samples were done by use of sterile distilled water to get the countable colonies. The dilution used was 10^{-2}. Aseptic transfer of 1ml of the 10^{-2} diluted water sample was done in a clean petri dish using sterile pipette. About 20 ml of melted MacConkey Agar medium was put to petri dishes containing the sample then being melted to 45-50˚C. Melted MacConkey Agar medium was then put to the petri dishes containing water samples and mixed well. The plates were then incubated at 37˚C for 24 hours.

3.8.2 Enumeration of coliform bacteria

After incubation, colonies characteristic of coliform bacteria was observed and counted. Pink colonies appearing on the MacConkey agar were considered coliform bacteria.

The number of colonies was recorded and expressed as colony forming unit per millilitre (CFU/ml).

The coliform count was calculated using a formula:

CFUU/ml= number of colonies x dilution factor – volume plated

Where

CFU/ml= colony forming units per millilitre

Dilution factor = dilution used during serial dilution

Volume plated= volume of sample inoculated.

3.9 Data Analysis

The data from the physicochemical and microbiological analyses were documented and tabulated using Microsoft Excel. Mean values were obtained for all the analysed parameters. The result was interpreted against the accepted standards for irrigation water quality. Throughout the study, the results were presented in tables to show temporal changes.

For analysis of study, Completely Randomized Design (CRD) was used. The ten sampling points (S1-S10) were considered as treatments. Three replications' observations were done on each sampling point during each sampling week. Variance Analysis (ANOVA) was conducted using GenStat statistical software package to ascertain the existence of significant difference between the sampling points on the parameters analysed.

Where significant differences occurred, treatments mean were grouped using the Least Significant Difference (LSD) test at 5% level of significance ($p \leqslant 0.05$). Descriptive statistics such as means, standard error of difference (SED) and coefficient of variation (CV%) were done to describe the data.

Total coliforms were quantified as colony forming unit per millilitre (CFU/ml). The analysis of the total coliforms followed the same procedure as for the physicochemical parameters. The result was presented in tables.

3.10 Ethical considerations

Permission was obtained from farmers using the dam before collecting water samples. The study ensures that sampling activities did not interfere with irrigation practices. Data collected were used strictly for academic purposes. No harmful chemicals were introduced into the water during sampling.

CHAPTER 4

RESULTS

4.1 Effects of treatment on temperature of water samples.

The outcomes shown in table 4.1 revealed that there was no significant difference in water temperatures at all sampling points for weeks 1 and 2($p>0.05$). There was significant difference in water temperature from week 3 to week 4 ($p<0.001$). In general, water temperature reduced from 25.13˚C at week 1 to 23.70˚C at week 4.

Table 4.1 Effects of Temperature (˚C) of Water Samples week 1, 2, 3 and 4

Sample point	Week 1	Week 2	Week 3	Week 4
S1	25.167^{a}	24.80^{b}	25.03^{ab}	23.833^{a}
S2	25.100^{a}	26.10^{a}	25.033^{ab}	23.867^{a}
S3	25.033^{a}	24.77^{b}	25.133^{a}	23.767^{ab}
S4	25.167^{a}	24.80^{b}	24.967^{b}	23.733^{b}
S5	25.167^{a}	24.70^{b}	24.833^{b}	23.700^{b}
S6	25.067^{a}	24.77^{b}	24.733^{bc}	23.667^{b}
S7	25.133^{a}	24.73^{b}	24.800^{b}	23.700^{b}
S8	25.167^{a}	24.67^{b}	24.700^{bc}	23.600^{c}
S9	25.167^{a}	24.70^{b}	24.600^{c}	23.567^{c}
S10	25.100^{a}	24.63^{b}	24.600^{c}	23.53^{c}
Grand Mean	25.127	24.870	24.843	23.697
SED	0.0667	0.5820	0.0577	0.0394

LSD (5%)	0.1391	1.2150	0.1204	0.0823
CV (%)	0.3	2.90	0.3	0.2
P-values	0.413ns	0.39ns	<0.001	<0.001

Means followed by the same later within a column are not significantly different at $p \leq 0.05$

4.2 Effects of Treatment on Electrical Conductivity (EC) of water samples.

As seen from Table 4.2, EC did not show any statistically significant variation among sampling points in week 1 (p=0.061) though the highest EC value was recorded for S3. Significant differences in EC values were observed from week 2 onward (p <0.001). S5 and S6 recorded the highest EC value in week 2, S4 and S7 showed highest EC value in week 3, whereas the highest EC value was recorded by S8 and S9 in week 4. The CV values (2.9-9.9%) indicate an acceptable variability of experiment.

Table 4:2 Effects of Electrical conductivity (EC) on water samples week at 1, 2, 3 and 4

Sample point	Week 1	Week 2	Week 3	Week 4
S1	237.3^{c}	240.3^{f}	236.0^{f}	265.7^{b}
S2	269.3^{b}	266.3^{d}	277.3^{c}	249.7^{c}
S3	316.3^{a}	260.7^{d}	285.0^{b}	243.7^{cd}
S4	274.0^{b}	263.7^{d}	293.3^{a}	252.3^{c}
S5	269.0^{b}	294.3^{a}	275.0^{c}	257.7^{bc}
S6	267.7^{b}	295.0^{a}	271.0^{c}	228.0^{d}
S7	294.3^{a}	272.7^{c}	288.3^{ab}	213.3^{e}
S8	255.7^{bc}	274.7^{c}	269.3^{c}	276.7^{a}
S9	261.3^{b}	272.3^{c}	249.7^{d}	270.3^{a}
S10	243.0^{c}	273.0^{c}	247.7^{e}	235.0^{d}
Grand Mean	268.8	271.3	269.3	249.2

SED	21.73	6.32	8.33	7.83
LSD (5%)	45.32	13.18	17.39	16.32
CV %	9.90	2.90	3.80	3.80

Means followed by the same later within a column are not significantly different at $p \leq 0.05$.

4.3 Effects of pH of Water Samples.

From the results presented in Table 4.3, it is clear that there is a significant difference between the levels of pH from various sampling points during the whole duration of the experiment ($p<0.001$). S10 and S9 had the highest value of pH, while s6 and s7 had the lowest one. Low values of CV (1.6-3.3%) demonstrate the reliability of the experiment.

Table 4:3 Effects of Treatment of pH of Water Samples at week 1, 2, 3 and 4.

Sample Point	Week 1	Week 2	Week 3	Week 4
S1	7.400^{c}	7.500^{d}	7.467^{d}	7.467^{d}
S2	8.267^{b}	7.667^{cd}	7.900^{c}	8.267^{b}
S3	8.833^{ab}	7.833^{c}	8.033^{bc}	8.067^{bc}
S4	9.200^{a}	7.033^{e}	7.833^{c}	7.200^{e}
S5	8.900^{a}	7.667^{cd}	8.067^{bc}	7.733^{cd}
S6	7.033^{c}	6.800^{e}	7.567^{d}	7.500^{d}
S7	8.000^{b}	6.600^{e}	6.600^{e}	6.500^{f}
S8	8.100^{b}	7.333^{d}	7.733^{c}	7.600^{cd}
S9	7.733^{a}	8.967^{a}	8.967^{a}	9.233^{a}
S10	8.500^{b}	9.133^{a}	8.867^{a}	8.933^{a}
Grand Mean	8.197	7.653	7.903	7.850
SED	0.2226	0.1719	0.1054	0.1897

LSD (5%)	0.4644	0.3586	0.2199	0.3958
CV%	3.30	2.80	1.60	3.00
P-value	<0.001	<0.001	<0.001	<0.001

Means followed by the same later within a column are not significantly different at $p \leq 0.05$.

4.4 Effects of Treatments of Water Sample Type on Microbial Counts.

Mean microbial counts (log CFU/ml) of samples S1-S10 is presented in Table 4. It was found out from analysis of variance that no difference existed ($p>0.05$) among the samples for CFU/ml week 1, CFU/ml week 2, CFU/ml week 3 and CFU/ml week 4. The corresponding p-value were 0.939, 0.444, 0.250 and 0.458, respectively.

The mean value for CFU/ml varied between 3.297 in sample S5 and 3.657 in sample S2 and S4 with a grand mean of 3.487. Coefficient of variation (CV) was 10.6% which is an indication of moderate variability of observations.

Mean value of CFU/ml at week 2 was the highest in sample 3 (3.520) and the lowest in sample 10 (2.860). The grand mean of CFU/ml at week 2 was 3.261 and the coefficient of variation was 11.4%.

The highest mean value of CFU/ml at week 3 was recorded in sample 10 (3.883) and the lowest in sample S8 (3.350). Grand mean of CFU/ml at week 3 was 3.63

For CFU/ml at week 4, sample S10 recorded the highest mean value (3.910), whereas sample S9 recorded the lowest value (3.347). The grand mean for this parameter was 3.573 and the coefficient of variation was 8.2%.

All treatments means were assigned the same latter (a), indicating that the differences observed among samples were not statistically significant at the 5% probability level.

Therefore, the microbial population of the sample were statistically similar across all four measurements.

Table 4:4 Effects of treatments of Water Samples on CFU/mL at week 1, 2, 3 and 4

Treatments	Week 1	Week 2	Week 3	Week 4
S1	3.577[a]	3.213[a]	3.593[a]	3.613[a]
S2	3.653[a]	3.273[a]	3.413[a]	3.553[a]
S3	3.553[a]	3.520[a]	3.630[a]	3.550[a]
S4	3.653[a]	3.183[a]	3.713[a]	3.417[a]
S5	3.297[a]	3.427[a]	3.767[a]	3.667[a]
S6	3.440[a]	3.373[a]	3.763[a]	3.390[a]
S7	3.457[a]	3.283[a]	3.650[a]	3.733[a]
S8	3.380[a]	3.513[a]	3.350[a]	3.547[a]
S9	3.543[a]	2.963[a]	3.613[a]	3.347[a]
S10	3.320[a]	2.860[a]	3.883[a]	3.910[a]
Grand mean	3.487	3.261	3.638	3.573
SED	0.3017	0.3028	0.1924	0.2383
LSD (5%)	0.6294	0.6315	0.4014	0.4971
CV%	10.6	11.4	6.5	8.2

P-value	0.939	0.444	0.250	0.458

Means followed by the same later within a column are not significantly different at $p \leq 0.05$.

CHAPTER 5

DISCUSSION OF RESULTS

5.1 Discussion of physicochemical parameters.

5.1.1 Temperature

Water temperature was fairly consistent during the study despite differences observed during certain sampling points. Temperature affects biological processes, nutrient cycling and the chemical composition of water. The slight variation of temperature between sampling points could be because of similar climatic factors and equal exposure of all points to the sun's rays. This observation is consistent with findings of Dalu et al., (2018) who noted that variations in temperatures in the reservoirs are mainly affected by climatic factors and activities of people near water bodies. Temperature stability is good since it helps in the consistency of biological and chemical reactions in the water body hence making it fit for irrigation purposes (FAO, 2020).

5.1.2 pH

There were significant variations ($p \leq 0.05$) in pH levels at the different sampling locations across the sampling periods. The variation in the pH level reveals a difference in the chemical properties of the surface water source. Variation in pH level can be linked to the presence of

dissolved components, microorganism activities, and decomposition of organic materials in the water sources. Generally, recorded pH levels were in good range for irrigation water as supported by Ayers and Westcot (1985), ranging between 6.5 and 8.4. Nevertheless, some sampling points registered higher pH levels, revealing alkaline conditions, which affect nutrient availability such as phosphorus, iron, and zinc in the soils irrigated with such water. The results are in agreement with Ayers and Westcot (1985), who noted that high alkalinity levels in irrigation water can influence nutrient availability. The pH level variations are also supported by the findings of Bilali and Taleb (2020), where the quality of the irrigation water depends on environmental and land use practices.

5.1.3 Electrical Conductivity (EC)

EC values varied significantly among sampling sites in the majority of sampling events. EC is a key parameter in terms of determining the concentration of dissolved salts and is commonly used to assess the risks of salinity in irrigation water (abidi *et al*.,2015). Variation in the EC values of the different sites implies variation in the salinity level and dissolved ionic content in the water samples. When the value of EC is higher there are higher risk of salt accumulation in the soil when such water is continuously used for irrigation purposes. However, the values of EC recorded in the current study indicate that the water sources have moderate levels of dissolved salts, thus making them suitable for irrigation purposes as long as proper irrigation practices are applied. These findings are similar to those reported by Ubar *et al*., (2020), where irrigation water with low to moderate EC values posed very little risks of salinity on plants.

5.2 Discussion of biological parameters.

Microbial analysis based on colony forming units (CFU/mL) it gave no significant difference ($p>0.05$) among sampling sites during all four periods. Although numerical differences were observed among sites, these differences were not statistically significant. This suggest that

microbial contamination level was relatively uniform across the sampled surface water source. The absence of significant difference may indicate that the water source was exposed to similar environmental conditions and contamination source. Agricultural runoff, animal activities and natural environmental factors may have contributed equally to microbial population across the sampling sites. The relatively moderate coefficients of variation obtained during the study further indicate consistency in microbial measurements.

These findings agree with Akinde et al., (2016), who reported that microbial contamination in irrigation water is often associated with diffuse contamination sources such as runoff and animal activities. Similarly, Gelting et al., (2015) observed that surface water sources used for irrigation may exhibit widespread microbial contamination when exposed to similar environmental influences. Although microbial counts were relatively stable across sampling locations, the presents of coliform bacteria remain important because irrigation water can serve as a pathway for transmitting pathogenic microorganism to crops, particularly vegetables consumed raw (Stele and Odumeru,2022; Akide et al.,2016). However, the presence of microbial population in irrigation water may serve as a vehicle for the transmission of plant and human pathogens particularly when used to horticultural crops.

5.3 Relationship between physicochemical and biological parameters.

Variations in pH, electrical conductivity, and temperature affect the growth and survivability of microbes in aquatic environment. The temperature affects metabolism of microbes whereas pH affects the growth and survival of many microorganisms. The electrical conductivity gives an indication of dissolved salt content that might also affect microbial activity (Alavaisha *et al*., 2019).

Despite significant differences being found in some physicochemical parameters, there was no considerable variation in microbial population at different sample locations. It appears that

the differences in the physicochemical parameters were not enough to create a significant variation in microbial population. Similar results were obtained by Alavaisha *et al*., (2019) where it was shown that changes in water quality parameters might not cause any changes in microbial population.

5.4 Implications for irrigation water quality.

Combined assessment of physicochemical and biological parameters shows that the sampled surface water sources were generally good for irrigation. The pH values were largely within the recommended range for irrigation water, while EC values indicated low to moderate salinity risk. According to FAO (2020) and Ayers and Westcot (1985), water with these characteristics is generally considered suitable for irrigation production. The absence of significant difference in microbial populations suggest relatively uniform microbiological conditions throughout the water source.

However, continued monitoring remains essential because irrigation water quality can change over time due to evaporation, runoff, agricultural activities and seasonal climatic variations (Shearan et al., 2021; Chemura et al., 2014). Regular assessment will help prevent potential problems related to salinity, nutrient imbalance and microbial contamination, thereby supporting sustainable irrigation and crop production in Bindura.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

This study was done to assess the quality of irrigation water obtained from SOS dame as the selected water source, using physicochemical and biological parameters. The results demonstrated that pH, electrical conductivity (EC) and temperature varied among the sampling sites and sampling periods. Significant difference was observed in pH throughout the study period, indicating spatial variations in the chemical characteristics of the water sources. Similarly, EC shows significant difference among sampling periods, suggesting variation in dissolved salt concentrations within the surface water source.

Temperature remained relatively stable throughout the study period, although significant difference was observed during the later sampling periods. The low coefficient of variation obtained for most physicochemical parameter indicated that the measurement was reliable and precise.

Biological analysis based on colony forming units (CFU/ml) revealed no significant difference among sampling sites throughout the study period. The finding suggest that the microbial population were relatively uniform across the sampled water source and that source was assumed to exposed to similar environmental conditions.

Overall, the results indicated that the quality of the assessed surface water sources varied primarily in terms of physicochemical characteristics, while biological characteristics remained the same across the site. The measured parameters generally indicated that the water were suitable for gardening or irrigation purpose although continued monitoring is necessary to prevent potential deterioration in water quality

6.2 Recommendations

1. Regular monitoring of irrigation water quality should be conducted to ensure that changes in physicochemical and biological parameters are detected.

2. Bindura smallholder farmers who use SOS dam for irrigation should periodically test water quality parameters more often to ensure safe agricultural production.

3. Measures should be implemented to minimize contamination of SOS dam water from agricultural runoff, livestock activities and other environmental pollutants.

4. Future investigations out to incorporate extra water quality indicators such as dissolved oxygen, TDS, nitrates, phosphate and heavy metals to enable a broader evaluation of irrigation water suitability.

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APPENDIX

Appendix 1: Analysis of variance

Variate: Temp_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
unit	9	0.065333	0.007259	1.09	0.413
Residual	20	0.133333	0.006667		
Total	29	0.198667			

Appendix 2: Analysis of variance

Variate: temp_2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
unit	9	5.1533	0.5726	1.13	0.390
Residual	20	10.1733	0.5087		
Total	29	15.3267			

Appendix 3: Analysis of variance

Variate: temp_w3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
unit	9	0.973667	0.108185	21.64	<.001
Residual	20	0.100000	0.005000		
Total	29	1.073667			

Appendix 4: Analysis of variance

Variate: temp_wk4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
unit	9	0.323000	0.035889	15.38	<.001
Residual	20	0.046667	0.002333		
Total	29	0.369667			

Appendix 5: Analysis of variance

Variate: EC_Wk1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

unit	9	14472.1	1608.0	2.27	0.061
Residual	20	14160.7	708.0		
Total	29	28632.8			

Appendix 6: Analysis of variance

Variate: EC_wk2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
unit	9	6792.97	754.77	12.61	<.001
Residual	20	1197.33	59.87		
Total	29	7990.30			

Appendix 7: Analysis of variance

Variate: EC_wk3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
unit	9	9745.9	1082.9	10.39	<.001
Residual	20	2084.0	104.2		
Total	29	11829.9			

Appendix 8: Analysis of variance

Variate: EC_wk4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
unit	9	10566.03	1174.00	12.78	<.001
Residual	20	1837.33	91.87		
Total	29	12403.37			

Appendix 9: Analysis of variance

Variate: ph_wk1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
unit	9	12.76300	1.41811	19.08	<.001
Residual	20	1.48667	0.07433		
Total	29	14.24967			

Appendix 10: Analysis of variance

Variate: ph_wk_2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
unit	9	18.88800	2.09867	47.34	<.001
Residual	20	0.88667	0.04433		
Total	29	19.77467			

Appendix 11: Analysis of variance

Variate: ph_wk_3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
unit	9	12.41633	1.37959	82.78	<.001
Residual	20	0.33333	0.01667		
Total	29	12.74967			

Appendix 12: Analysis of variance

Variate: phwek4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
unit	9	17.69500	1.96611	36.41	<.001
Residual	20	1.08000	0.05400		
Total	29	18.77500			

Appendix 13: Analysis of variance

Variate: CFU_ml_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

CITE	9	0.4489	0.0499	0.37	0.939
Residual	20	2.7313	0.1366		
Total	29	3.1802			

Appendix 14: Analysis of variance

Variate: CFU_ml week 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CITE	9	1.2875	0.1431	1.04	0.444
Residual	20	2.7497	0.1375		
Total	29	4.0373			

Appendix 15: Analysis of variance

Variate: CFU_ml week 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CITE	9	0.70307	0.07812	1.41	0.250
Residual	20	1.11087	0.05554		
Total	29	1.81394			

Appendix 16: Analysis of variance

Variate: CFU/ml week 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CITE	9	0.78132	0.08681	1.02	0.458
Residual	20	1.70367	0.08518		
Total	29	2.48499			

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