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Potential of selected microalgae in the bioremediation of wastewater impacted dam water: A case of Goreangab Dam in Windhoek, Namibia

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ABSTRACT

The study was aimed at determining the efficacy of freshwater microalgae in the treatment of polluted dam water with respect to the reduction of pathogen loads, as well as heavy metals and nutrients concentrations. Microalgae were collected from the Klein Windhoek River, as well as the Avis and Goreangab Dams in Windhoek, Namibia. Identification of the microalgae species revealed the presence of the Microcystis species in the Goreangab Dam (control), Anabaena species in the Klein Windhoek River (treatment 1) and the Scenesdesmus species as well as the Anabaena species in the Avis Dam (treatment 2). During treatment, the water samples were assessed on day 0, day 6 and day 12 for faecal and total coliform bacteria, heavy metals (Pb and Cd) as well as nutrients (phosphorous and nitrates). A one-way analysis of variance (ANOVA) indicated that there were no statistical differences between the mean values of Pb ($p = 0.346$) and Cd ($p = 0.940$) concentrations after treatment with microalgae. The Kruskal Wallis tests indicated statistical differences between the mean values of the nitrate levels ($H(3) = 8.597$, $p = 0.035$) before and after treatment with microalgae. However, the ANOVA indicated that there were no significant differences between the mean values of total phosphate uptake ($p = 0.052$) after treatment with microalgae. The results for pathogen loads in the wastewater samples indicated statistically significant differences between the mean values of total coliforms (($H(3) = 10.352$, $p = 0.015$) as well as faecal coliforms ($H(3) = 10.421$, $p = 0.015$) before and after treatment with microalgae. We conclude that while our microalgae species were not effective in the removal of heavy metals from the dam water, they were nonetheless effective in the removal of microbial contaminants as well as excessive nutrients from wastewater.

1. Introduction

Multiple environmental and anthropogenic stressors such as pollution and climate change are putting water security under threat, especially in arid and semi-arid regions (Kahil et al., 2015). Pollution of water limits the different ways of water usage since its availability is linked to its quality (UNESCO, 2017). Notable sources of water pollution include discharge of effluents from urban wastewater treatment plants into surface water bodies, including rivers and dams (Abdel-Razek et al., 2019), as well as anthropogenic activities such as urban development, industrialization and agricultural activities (Zhao et al., 2012). Wastewater discharges contain inorganic compounds that often result in water eutrophication and ecosystem imbalance, as well as pathogenic microorganisms and heavy metals that render such water bodies a threat to both public and ecological health (Abdel-Razek et al., 2019).

The pollution of water resources exacerbates water scarcity challenges in countries like Namibia that are already regarded as water scarce. The country is the driest in sub-Saharan Africa, with a very hot and dry climate characterised by low and highly variable annual rainfall patterns (Scott et al., 2018). Temperatures in Namibia have been on an increasing trend since the 1970s (Dirkx et al., 2008). The country experiences high evaporation rates with losses of up to 97% of rainfall through evaporation. Windhoek, the country's capital city, experiences an average annual rainfall of only 360 mm (Namibia National Weather Bureau, 2003). In recent times, the extreme droughts of 2015 and 2017 placed a severe strain on the City of Windhoek's (CoW) capacity to provide clean, fresh drinking water to its inhabitants (Scott et al., 2018). As a result, water pollution has been identified by CoW as one of the driving forces contributing to limited water supplies. A case in point is the decommissioning of the Goreangab Dam in 2010.

The Goreangab Dam water is heavily polluted due to the discharge of effluents rich in organic matter and heavy metals from the City of

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Windhoek (Faul et al., 2013). Due to the mentioned pollutants, the quality of the dam water fails to meet the national standard criteria (Du Pisani, 2006). Studies indicate that the dam is eutrophic and causing fish kills and low macrophtye abundance (Nangolo, 2018). In its current polluted state, the Goreangab Dam also represents a public health concern because of some potential waterborne pathogens, including bacteria, viruses and protozoa (Shilikomwenyo, 2019).

Lehmann (2010) stated that the water scarcity stress on the CoW is worsened by the current water pollution of the Goreangab Dam. Hence, there is a high need to explore innovative clean-up methods such as bioremediation in order to eliminate the public and ecological health risk posed by the polluted water, as well as to restore the dam's status as one of the CoW's supply dams. To my knowledge, there are currently no scientific studies directed towards the rehabilitation of the Goreangab Dam, hence this study.

This study focuses on the Goreangab Dam in Windhoek, Namibia, providing valuable insights into the potential application of microalgae for bioremediation in a region with distinct environmental challenges and socioeconomic factors. Further, the research presents a detailed investigation into the potential of selected microalgae strains indigenous to the region for wastewater remediation, including their growth characteristics, nutrient uptake efficiency, and tolerance to environmental stressors. This aspect of the study adds to the existing knowledge base by offering specific insights into the performance of locally adapted microalgae species. Further to the above, the findings of this study have practical implications for the development of cost-effective and sustainable wastewater treatment strategies tailored to the needs of communities in water-stressed regions such as Windhoek, Namibia. By elucidating the bioremediation potential of microalgae, the research contributes to the ongoing efforts to mitigate water pollution and enhance water quality.

The limitation of this study was that as an ex-situ experiment there was an initial challenge in growing the microalgae species outside of their natural environment and finances were also a limiting factor, as it was a self funded project and wster quality nalysis tests are quite costly in Namibia.

1.1. Objectives

The dam used to serve as one of the sources of abstraction water for the drinking water treatment plant that supplies the city but has since been decommissioned owing to its unprecedentedly high pollution loads, with organic matter, nutrients, and heavy metals as the primary pollutants (Faul et al., 2013).

While attempting to purify excessively polluted water using conventional means may be uneconomical and unsustainable, research shows that the use of green microalgae could be an economical and environmentally friendly alternative in the bioremediation of wastewater as well as polluted water (Kshirsagar, 2013). Bioremediation is the process in which living organisms such as microalgae are used to eliminate toxic contaminants (Kensa, 2011). Microalgae facilitates bioremediation through its photosynthetic activity which allows it to convert solar energy into biomass, assimilating nutrients such as nitrogen and phosphorus which are responsible for eutrophication. Besides, microalgae mediated water treatment is advantageous in terms of better pathogen and heavy metal removal, as well as generation of energy rich algal biomass (Kshirsagar, 2013). Therefore the aim of the study was to determine whether treatment of the polluted Goreangab Dam water with various species of freshwater microalgae could significantly reduce its total and faecal indicator bacteria loads, as well as the concentrations of heavy metals and nutrients.

2. Materials and method

2.1. Description of study area

The study was conducted in Windhoek, Khomas Region, Namibia. Algal samples were obtained from three sites, namely Goreangab Dam (22.5286 ° S, 17.0087 ° E), Avis Dam (22.5741 ° S, 17.1288 ° E) and Klein Windhoek River (22.3471 ° S, 17.0509 ° E). The polluted water for the bioremediation assays was obtained from Goreangab Dam. The Goreangab Dam is located in the north-western suburbs of Windhoek which is the capital city of Namibia (Ogunmokun et al., 2000). The dam once served as a source of raw water for Windhoek's drinking treatment plant since its commissioning in 1958 until it was decommissioned in 2010 due to its polluted state (Du Pisani, 2006). The dam receives effluent from the Gammams Wastewater Treatment Plant. The Avis Dam, on the other hand, is Windhoek's first dam, and is situated approximately 9 km east of Windhoek. It was constructed in 1933 for the supply of water to the City of Windhoek (Crovello et al., 2010). The dam, however, failed to sustainably supply enough water due to its small catchment area (Hamata and Chinsembu, 2012). And lastly, the Klein Windhoek River is a seasonal river that originates in Ludwigsdorf from where it then flows in a general north western direction from Windhoek until it empties into the Otjiseru River which is located between Windhoek and Okahandja.

2.2. Sampling

Water from the Goreangab Dam was collected using 25 L plastic containers. These containers were first washed with disinfectant followed by double rinsing with Goreangab Dam water before sample collection, as described by Cornman et al. (2018). The grab sampling method was employed by submerging the containers to collect water directly into the containers at knee depth.

For microalagae sampling, BG-11 (Blue Green) media was prepared prior to site visit and readied for use as enrichment for the growth of green freshwater microalgae following the descriptions of Ilavarasi et al. (2011). Microalgae samples were collected by suctioning them into appropriately labelled 1 L sterile bottles together with about 500 mL of freshwater. The percentage increase after the addition of the BG- 11 media to the freshwater microalgae was 20%.

Samples were taken to the laboratory at the University of Namibia for further processing.

2.3. Research procedure

A quantitative research design was employed. The experimental design included 9 experiments and their controls. Experiments were carried out in Erlenmeyer flasks containing 2000 mL of water from the Goreangab Dam in which the microalgae species from the Avis Dam and Klein Windhoek River were inoculated. No external microalgae species were inoculated for the control.

The flasks were placed on a laboratory shaker which was set at 150 RPM, which was placed in the greenhouse located in the Department of Biochemistry, Microbiology and Biotechnology at the University of

Namibia. The shaker was left to run for a period of 12 days from April 21, 2021 to May 03, 2021. It provided microalgae turbulence which is an important factor in wastewater treatment and microalgae grow well at turbulence between 100 and 200 RPM (Larsdotter, 2006). Furthermore, the greenhouse provided essential physical factors such as light and moderately steady temperatures which are needed for microalgal growth (Larsdotter, 2006). The water samples were analysed for nutrient levels, heavy metal concentrations and for the presence of coliform bacteria before and after treatment.

2.4. Microalgae identification

Some of the microalgae samples from the Avis Dam, Klein Windhoek River and the Goreangab Dam were grown in BG 11 medium for identification. These algae samples were first kept in the greenhouse for a week for optimum growth before they were sent to the NamWater Laboratory (Windhoek) for identification. NamWater's analytical laboratory identifies algae based on national and international accepted protocols (Vo et al., 2019). Microalgae were isolated using the membrane filtration technique. The membrane filters were then allowed to dry, after which they were placed on microscope slides with immersion oil and observed under a microscope. The microalgae were then identified by comparison to a phytoplankton identification book for microscopic algae in Southern African freshwaters (Vuuren et al., 2006).

2.5. Water quality analysis

Temperature influences the physical, chemical and biological processes of water bodies (Nangolo, 2018). Therefore, the temperature of the wastewater samples was monitored using a thermometer three times daily.

Water samples were analysed for lead, arsenic and cadmium using the ICP-OES (Inductively coupled plasma - optical emission spectrometry) technique (Chochorek et al., 2010). For this technique, the water samples were filtered followed by acidification to a pH less than 2 with ultrapure nitric acid (HNO_3) 16 h before the ICP-OES analysis.

Furthermore, nitrate, nitrite/total nitrogen determination of the water samples was based on the hydrazine reduction method as described by Bower and Holm-Hansen (1980). This method reduces nitrate to nitrite using hydrazinium sulfate. The reduced nitrate was determined by diazotisation with sulfanilamide and coupling with N-(1-naphthyl) ethylenediamine dihydrochloride to form a highly coloured azo dye which was then measured. And the phosphate cell test was used to analyse the phosphorus content for the water samples, as described by Stalder and Zumbuehl (2013). Briefly, 50 ml of each water sample was separately mixed with 11 N sulphuric acid and 4 ml of ammonium molybdate-antimony potassium tartrate and thorough mixed before 2 ml of ascorbic acid were added to the solution and further mixed. After 5 min, the absorbance of the solution was determined.

2.6. Daily coliform observation

Eosin methylene blue agar (EMB) was used to grow faecal coliforms. This is a differential medium used for the isolation of faecal coliform bacteria (Lal and Cheeptham, 2007). Exactly 100 μl of each sub sample were spread on the agar plates and placed in the incubator at a temperature of 45.0 ± 0.2 ° C for 24 h and prepared and observed daily. Sub-sampling for coliform observation was done daily. While *m*-Endo agar was used to grow total coliforms in the incubator at a temperature of 37 ± 0.5 ° C for 48 h, prepared and observed every second day. The spread plate method was used to isolate and count total and faecal coliforms because it makes bacteria easier to count (Lal and Cheeptham, 2007).

Table 1
Algae identification report.

Microalgae sample site	Microalgae species present
Goreangab dam	*Microcystis*
Klein Windhoek River	*Anabaena*
Avis dam	*Anabaena, Scenedesmus*

3. Results

3.1. Microalgae identification

Microalgae identification confirmed the presence of Microcystis species, Anabaena species and Scenedesmus species in the water samples as indicated in the table below (Table 1). The Goreangab Dam sample consisted of naturally occurring Microcystis species. These control samples that were not inoculated with external microalgae were still analysed and monitored for the performance of the Microcystis species in bioremediation (the constant of the experiment). The Klein Windhoek River sample (Treatment 1) consisted of the Anabaena species. The Avis Dam sample (Treatment 2) consisted of the Anabaena species as well as the Scenedesmus species. The consortium of this experiment consisted of water samples inoculated with all the microalgae species. The Microcystis and Anabaena species belong to the phylum Cyanophyta commonly known as blue green algae that obtain energy through photosynthesis (Nweze, , 2009). The Scenedesmus species belong to the phylum Chlorophyta commonly known as green algae (Baudelet et al., 2017).

3.2. Temperature

The average temperature of the water samples decreased from 33 °C on the first day, to 30 °C on the 6th day and then 27 °C on the last day of the experiment, see Fig. 1 below.

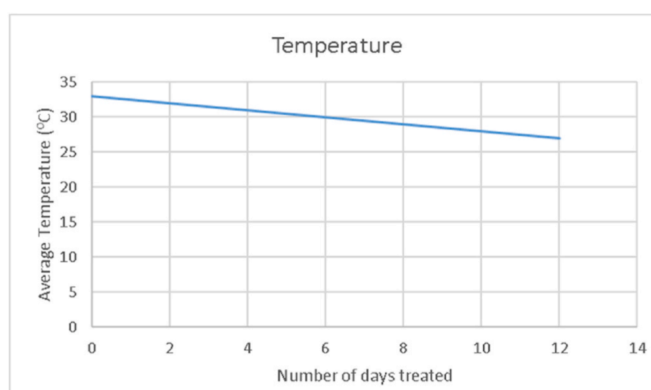

Fig. 1. Average temperature of water samples from the Goreangab dam treated with green microalgae for 12 days. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.3. Heavy metals

The Cadmium (Cd) level of the water samples from the Goreangab Dam was 0.02 mg/L on the first day of the experiment. After the microalgae species were inoculated into the water samples, a decrease in the Cd level of the wastewater was observed as depicted in the graph below (Fig. 2). The Shapiro Wilk test ($P<0.05$) showed that the data for Cd concentration were not normally distributed. Treatment 1, treatment 2 and the consortium all had the same levels of Cd content from the beginning to the end of the experiment. The Cd levels in the water samples for treatment 1, treatment 2 and the consortium have showed an immediate steep decline from 0.02 mg/L on the first day to 0.01 mg/L on the sixth day, the Cd levels remained constant at 0.01 mg/L until the last day of the experiment. On the other hand, the control samples which only consisted of the natural occurring *Microcystis* species illustrated a slower decline starting and remaining at 0.02 mg/L Cd level on the first day through to the sixth day and then steeply declined to 0.01 mg/L on the last day.

However, although there was a decline in Cd levels after treatment the Kruskal Wallis test indicated that there were no statistical differences between the mean values ($p = 0.940$) before and after treatment with microalgae.

The Lead (Pb) level of the water samples from the Goreangab Dam was 0.8 mg/L on the first day of the experiment. After the microalgae species were inoculated into the water samples, a decrease in the Pb level of the water was observed as depicted in the graph (Fig. 3) below. However, after treatment with microalgae the Pb levels of the control water samples consisting of the natural occurring *Microcystis* species indicated a high removal of Pb compared to the water samples of treatment 1, 2 and the consortium. The Shapiro Wilk test ($P > 0.05$) showed that the data for Pb concentrations were approximately normally distributed. However, the one-way analysis of variance (ANOVA) indicated that there are no statistical differences between the mean values ($p = 0.346$) before and after treatment with microalgae. And the Welch and Brown-Forsythe test further agreed with no statistical differences between the means with the values of $p = 0.08$ and $p = 0.381$ respectively. But it is important to note that the *Microcystis* species has indicated the ability to reduce the Pb content of the water samples below 0.01 mg/L.

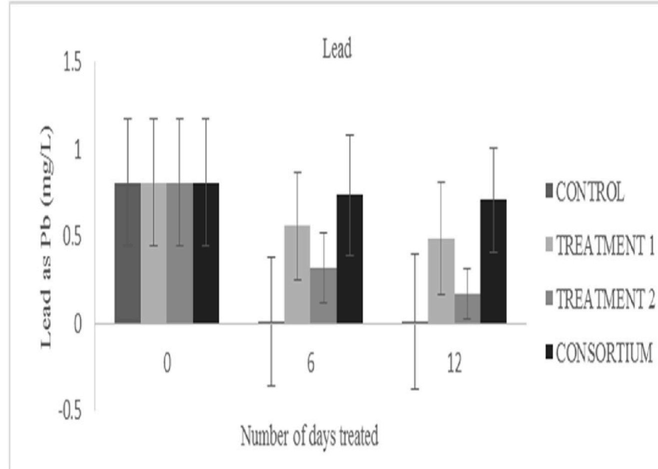

Fig. 3. Lead content in water samples from the Goreangab dam treated with green microalgae for 12 days.

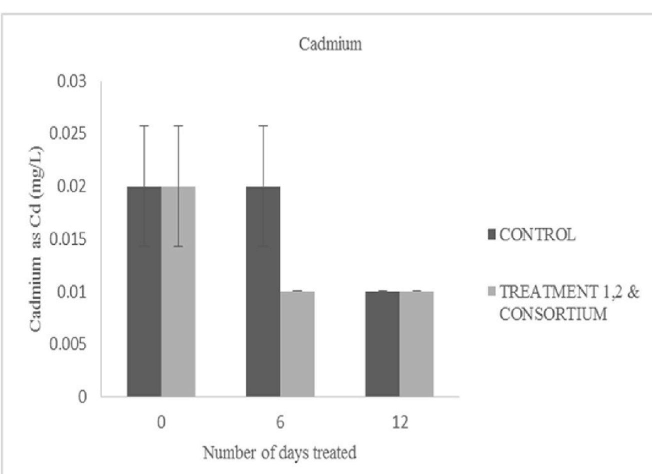

Fig. 2. Cadmium content in water samples from the Goreangab dam treated with green microalgae for 12 days.

3.4. Nutrients

The results in the graph (Fig. 4) below show that the water samples for treatment 2 indicated the fastest uptake of nitrates (from 2.5 mg/L to 0.5 mg/L) followed by the consortium, then the control water samples. Treatment 1 water samples showed a relatively low uptake of nitrates from the wastewater. The Shapiro Wilk test ($P<0.05$) showed that the data for nitrate levels were not normally distributed and the Kruskal Wallis test indicated that there were statistical differences between the mean values ($H(3) = 8.597$, $p = 0.035$) of the nitrate levels after

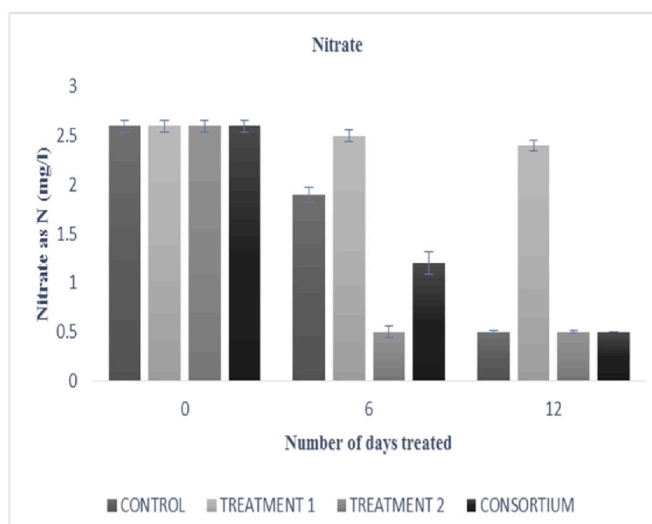

Fig. 4. Nitrate content in water samples from the Goreangab Dam treated with green microalgae for 12 days.

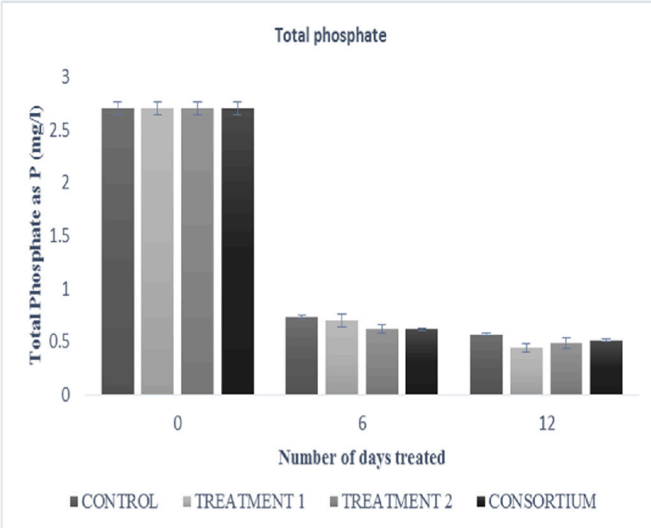

Fig. 5. Total Phosphate content in water samples from the Goreangab Dam treated with green microalgae for 12 days.

treatment with microalgae. Pair Wise Comparisons indicated significant differences in nutrient uptake between treatment 1 which was the least effective in nitrate uptake and treatment 2 which was the most effective ($p = 0.005$) and there were also significant differences between the control and treatment 1 ($p = 0.039$). No significant differences were detected between the other groups.

Phosphate uptake as illustrated by the graph (Fig. 5) above indicate that the total phosphate uptake amongst the three treatments and the control are relatively similar. Ranging from a total phosphate uptake of 2.70 mg/l at the beginning of the experiment to 0.44 mg/l at the end of the experiment. Treatment 1 was the most effective group in the uptake of phosphate from the water samples from the Goreangab Dam.

However, the Shapiro Wilk test ($P > 0.05$) showed that the data for total phosphate levels were approximately normally distributed but the ANOVA indicated that there were no significant differences between the mean values ($p = 0.052$) before and after treatment with microalgae.

3.5. *Coliform presence*

3.5.1. *Total coliform*

The Shapiro Wilk test ($P<0.05$) showed that the data for total coliform presence were not normally distributed and the Kruskal Wallis test indicated that there are statistical differences between the mean values (($H(3) = 10.352$, $p = 0.015$) before and after treatment with microalgae.

The Pair Wise Comparisons indicated significant differences in total

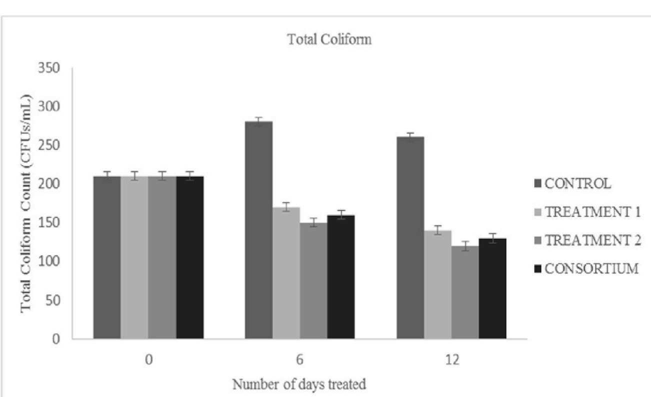

Fig. 6. Total Coliform count in water samples from the Goreangab Dam treated with green microalgae for 12 days.

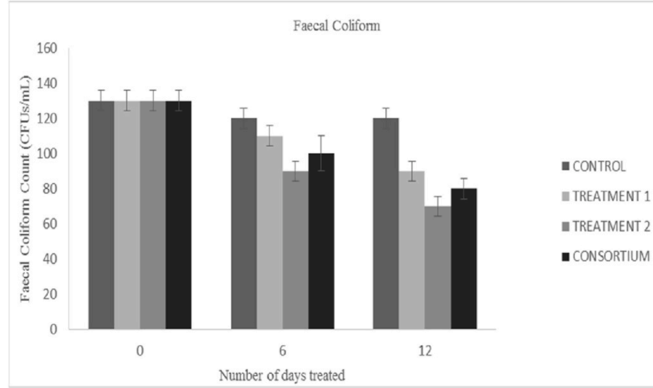

Fig. 7. Faecal Coliform count in water samples from the Goreangab Dam treated with green microalgae for 12 days.

coliform removal between the control which was the least effective and treatment 2 which was the most effective ($p = 0.002$), there were also significant differences between the control and the consortium ($p = 0.040$) and between treatment 1 and treatment 2 ($p = 0.040$), see Fig. 6 above.

3.5.2. *Faecal coliform*

The Shapiro Wilk test ($P<0.05$) showed that the data for faecal coliform presence were not normally distributed and the Kruskal Wallis test indicated that there are statistical differences between the mean values (($H(3) = 10.421$, $p = 0.015$) before and after treatment with microalgae. For the three experiments and the controls, a decline in the concentration of faecal coliforms in the wastewater samples, were, observed (Fig. 7). More in the water samples with external microalgae inoculated. Treatment 2 was the most effective in faecal coliform removal and the control the least. The Pair Wise Comparisons indicated significant differences in faecal coliform removal between the control which was the least effective and treatment 2 which was the most effective ($p = 0.002$), there were also significant differences between the control and the consortium ($p = 0.041$) and between treatment 1 and treatment 2 ($p = 0.041$).

4. Discussion

4.1. *Heavy metals*

During this study the microalgae species did not significantly remove Cd and Pb from the water samples of the Goreangab Dam. While research indicates that algae such as Cyanobacteria *Microcystis* and *Anabaena* have high metal binding affinity when compared to other microorganisms and are thus generally used for the removal of heavy metals from wastewater (Abdel-Aty et al., 2013), abiotic factors and organic matter can influence the absorption of heavy metals by these algae (Torres, 2016). For instance, temperature influences the metal biosorption efficiency of these algal species [(Chairat and Bremner, 2016); (Gupta et al., 2010)], with some studies showing that an increase in water temperature leads to a possible increase in metal ions biosorption [(Khan et al., 2012); (Yi et al., 2016)]. During this study, the water temperature decreased from 33 $^{\circ}C$ on the first day of the experiment to 27 ° C on the last day, why possibly explains the poor performance in metal absorption during the experiment, because a decrease in water temperature leads to a decrease in active sites involved in metal ions uptake, and a decrease in the affinity of these sites to absorb metal ions (Zhu and Wachs, 2016). A decrease in temperature also causes a change in the complex formation constant with temperature. However, it is important to note that different algae species behave differently during phycoremediation in heavy metal removal from wastewater [(Mantzorou et al., 2018); (Chang et al., 2019); (Furuhashi et al., 2019)].

The optimum temperatures for the three microalgae species used in the experiment were 25 °*C* for *Anabaena* (Kłodawska et al., 2019), and between 30 and 35 °*C* for *Microcystis* (Imai et al., 2009). However, there are conflicting results for *Scenesdesmus* species as some studies suggests 30 °*C* (Cassidy, 2011), while others state 37 °*C* (Cassidy, 2011). None of these optimal temperature conditions were attained during the current study, which highlights the importance of optimum water temperature in the removal of heavy metals by algae.

However, although the reduction of Pb from the water samples was not statistically significant, *Microcystis* species indicated moderate abilities to reduce Pb content from wastewater. When conditions are optimal, this species has been found to absorb Pb in high capacities as compared to other microalgae (Chang et al., 2019).

4.2. Nutrient analysis

The *Scenesdesmus* species requires large amounts of nutrients for growth and has hence, been successfully used as a biological treatment to remove nitrogen and phosphorus from wastewater [(Boelee et al., 2011); (Gonçalves et al., 2017)]. In the current study, the *Scenesdesmus* species was the most effective in the removal of nitrate from the water samples, and all the treatments that included this species (treatment 2 and consortium) performed well in the uptake of nitrate. The *Scenesdesmus* species, which falls under green algae, uses a diversity of nitrogen sources for growth. The algae is capable of converting a variety of inorganic nitrogen forms, including (nitrites, nitrates, ammonia, and ammonium-N), to organic nitrogen (Zhao et al., 2019). Several studies have indicated that nitrification and denitrification are the main processes by which algae systems remove nitrogen (Delgadillo-Mirquez et al., 2016). Our findings suggesting the successful use of the *Scenesdesmus* species in the removal of nitrate concur with the results of previous studies. For instance, (Ansari et al., 2019) shared that Scenedesmus species completely removed (100% reduction) nitrate from municipal wastewater. Another study also indicated that the *Scenesdesmus* species was able to rapidly reduce nitrate concentration from wastewater from 240 mg/L to 144.7 mg/L in 16 days (Ansari et al., 2019). These studies further support the abilities of the *Scenesdesmus* species in the removal of nitrates.

Treatment 1 and the control which were treated with the *Anabaena* species and the *Microcystis* species separately were the least effective in the removal of nitrate. This could be because cyanobacteria have selective preference to nitrogen sources as compared to the green microalgae species *Scenedesmus* (Park et al., 2010). Consequently, the *Scenesdesmus* species outcompetes the *Anabaena* species and the *Microcystis* species in nitrate uptake.

Overall, however, phosphate removal from the water samples was not stastically significant. While cyanobacteria are stated to grow best in eutrophic conditions that have high phosphorus concentrations (O Neil et al., 2012), (Sabour et al., 2009) have demonstrated that they can also develop under low phosphorus conditions they have a large storage capacity for phosphorus. This explains the similar uptake of phosphate across the different treatments and control because of the presence of cyanobacteria in all the water samples. Furthermore, other studies have indicated that *Anabaena* and *Microcystis* cyanobacteria use excess phosphorus for nitrogen fixation (Kramer et al., 2022). Phosphorus stimulates nitrification which is important for the removal of nitrogen from wastewater (Ning et al., 2021). Thus, cyanobacteria take up more phosphate compared to green algae because their cells not only store phosphorus but also use it in nitrogen fixation.

4.3. Pathogen loads

In various studies, microalgae have indicated the ability to remove pathogens when applied to wastewater (Gupta et al., 2010). Some studies have observed pathogen removal with prolonged algal cultivation with the *Scenesdesmus* species especially, which has shown a greater potential for pathogen removal (Gupta et al., 2010). This has also been the case in the current study, as all the water samples that were treated with the *Scenesdesmus* species demonstrated significantly higher removal of pathogens compared to the other treatments (treatment 1 and the control), which performed poorly. However, microalgae across all the treatments have indicated the ability to remove pathogens from the water samples.

Algae secrete metabolites which effect pathogens survival [(Kümmerer, 2008); (Saha and Weinberger, 2019)]. To the contrary, however, (Gupta et al., 2010) found that the effects of increased pH on coliforms removals in the absence of algae was significant. This shows that bactericidal effects of algal metabolites are the dominating factor for pathogen removal rather than just high pH levels. Case studies further shared the mechanisms by which algae are able to remove pathogens from wastewater as follows: algae out competes coliform bacteria for nutrients, hindering coliform growth; algae causes an increase in pH due to CO_2 consumption and this is lethal for pathogens; algae produces toxic long chain fatty acids which kill pathogens; algae adds O_2 to the water enhancing faecal coliform die-off rates; and coliform bacteria attach to the algal cells, making their removal easier based on the mentioned mechanisms [(Awuah, 2006); (Ahmad et al., 2014)].

5. Conclusion

The study indicated that under optimal conditions of temperature and pH, microalgae is able to reduce faecal indicator loads and nitrate levels of wastewater significantly. However, the study also observed that all three genera used, (*Microcystis*, *Anabaena* and *Scenesdesmus*), were not successful in significantly reducing the heavy metal and phosphate concentrations of the water samples.

Additionally, the results of the study further indicate that the *Scenesdesmus* species is highly effective in the treatment of organic wastes in polluted water, under optimal conditions. The algae species effectively reduced the nitrate levels and pathogen loads of the water samples of the Goreangab Dam. The study further indicate that the *Anabaena* and *Scenesdesmus* species worked well as consortia to treat nitrate concentrations and pathogen loads of the water samples. And although the *Microcystis* species produce toxins that can negatively influence the aquatic environment, the study showed that this species can still be used in a controlled environment to treat phosphate concerntration in wastewater, as these cyanobacteria survive well in excessive phosphate concerntrations.

Further to the above, we recommend that microalgae species need to be further investigated for their ability in the removal of organic matter from polluted water sources that can potentially serve as water supply systems which will aid in curbing the issue of water scarcity.

Genetic engineering approaches and scalable culture systems may be used to optimise microalgae strains for wastewater cleanup. To facilitate the incorporation of microalgae-based bioremediation systems into current wastewater treatment infrastructure, two approaches may be taken: modifying traditional treatment facilities or incorporating microalgae-based technologies into decentralised wastewater treatment systems in rural and peri-urban regions. These changes may greatly improve the relevance and practicality of using microalgae-based bioremediation as a sustainable approach for addressing difficulties in wastewater management.

CRediT authorship contribution statement

Jennifer M. Ndura: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. **Timothy Sibanda:** Writing – review & editing, Writing – original draft, Supervision, Project administration. **Earl Lewis:** Writing – review & editing, Writing – original draft, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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