Barriers to closing the loop on nutrient recycling–a case study on phycoremediation of domestic wastewater in South Africa

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1.0 Introduction

In 2015, the United Nations published the 2030 Agenda for Sustainable Development. Achieving the 17 Sustainable Development Goals (SDGs) would guarantee a balance between environmental, economic, and social aspects of development. Sustainable Development Goal (SDG) 6 not only focuses on drinking water and basic sanitation, but also includes the sustainable management of water, wastewater, and ecosystems. This goal specifically focuses on the essential role of water in addressing those challenges (e.g., poverty, education, and health) linked to water scarcity, water pollution, degraded water-related ecosystems, and cooperation over transboundary water basins (UNEP 2018b; United Nations 2020; UNEP, 2021; UN-Water, 2021). As part of SDG6, specific goals / targets have been identified to achieve sustainable development. One such goal (Target 6.3 of SDG 6) is to half the proportion of untreated wastewater released into water bodies globally (UN-Habitat and WHO, 2021). According to UN-Water (2021), an estimated 44% of household wastewater is not treated by secondary or higher treatment processes or treated to meet the relevant effluent guidelines or standards globally.

Africa's sanitation and wastewater infrastructure challenges are exacerbated by uncontrolled population growth and urban migration. While 38% of the African population is currently living in urban areas, rates of urbanisation growth are highest in Sub-Saharan Africa (5.8%) and predicted to double by 2030 (Bahri, 2007). Over 63% of South Africans are already living in urban areas (PMG, 2020). This implies that the existing sanitation and wastewater treatment and management challenges will likely also increase, giving rise to additional water security challenges. Given this reality, the World Bank in 2018 launched an initiative that called for a paradigm shift towards the circular economy, where wastewater is increasingly viewed as a valuable resource instead of a waste product. Figure 1 depicts how sustainable wastewater management can allow for resource recovery in the form of energy, reusable water, biosolids and nutrients, adding to economic benefits.

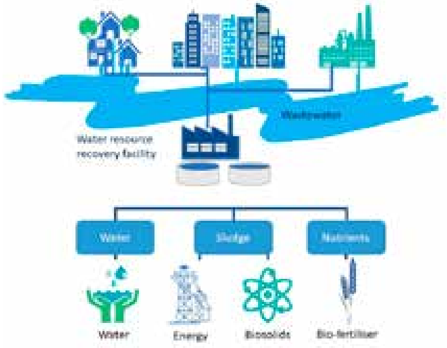

FIGURE 1

Figure 1: Economic benefits from resource recovery resulting from sustainable wastewater management (adapted from Rodriguez et al., 2020).

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In addition to the great potential to close the nutrient recycling loop, the circular economy can support cost recovery within the waste sector and can even help to create viable businesses. Nutrient recovery from organic waste streams is high on the development agenda and is also of great importance in view of diminishing non-renewable resources, such as phosphorus (Shaddel et al., 2019; Renuka et al., 2021). Furthermore, nutrient recovery from domestic wastewater extends beyond direct economic benefits to that of ecosystem and human health benefits. Following biological treatment or physicochemical separation, phycoremediation is one of the main practiced routes for capturing nutrients from wastewater (Shaddel et al., 2019) and provides an alternative low-cost green solution to nutrient recovery from wastewater streams in developing countries (Oberholster et al., 2019; Oberholster et al., 2021).

The use of algae for the removal of nutrients is not a new phenomenon and was first described in 1953 by Oswald and co-authors. Olguin, in 2003, described phycoremediation as "the process whereby macroalgae or microalgae bio-transforms or remove pollutants, including nutrients and xenobiotics, from wastewater and carbon dioxide (CO_2) from waste air". Internationally, phycoremediation has been successfully applied to different industrial wastewaters for example sugar processing effluent (Sailaja and Meti, 2014; Zewdie and Ali, 2020), paper and pulp effluent (Sasi et al., 2020), tannery waste (Hanumantha et al., 2011), and distillery effluent (Khrisnamoorthy et al., 2019). Similarly, phycoremediation has reportedly successfully decreased or eliminated heavy metal content of wastewaters (Kwarciak-Kozłowska et al., 2014; Koul et al., 2021), reduced antibiotic resistance (Michelon et al., 2021) and absorbed other emerging contaminants (e.g., endocrine disrupting chemicals, Personal care products and pesticides) (Gupta et al., 2015).

The photoautotrophic nature of the algae, which allow them to use CO_2 as their carbon source (Guldhe et al., 2015), makes phycoremediation an attractive low-cost alternative solution as the addition of an organic carbon source is not needed (Rao et al., 2011; Koul et al., 2021). The nutrients, phosphorous and nitrogen, which are readily available in domestic wastewater are essential for the growth of algae (Emparan et al., 2018; Bansal et al., 2018; Goswami et al., 2021; Koul et al., 2021). To date, various microalgae species (e.g., *Chlorella* spp. and *Scenedesmus* spp.) have been described to successfully remove nutrients from wastewater by several authors (Bansal et al., 2018; Queiroz et al., 2007; Rao et al., 2011; Renuka et al., 2021;). These species have high nutrient removal capabilities combined with a fast growth rate, making them good candidates to treat wastewater. At the same time, due to their high capacity for inorganic nutrient uptake (Bolan et al., 2004; den Haan et al., 2016) microalgae could produce potentially valuable biomass (Al-Jabri et al., 2021). Some of the multiple benefits that can be derived from microalgae biomass include amongst others, biofuel (Alam et al., 2012; Hannon et al., 2010), biogas (Debowski et al., 2013), and biofertilizer (Baweja et al., 2019; Guo et al., 2020). Since microalgae contains valuable compounds (e.g., fatty acids, and proteins), Fernandez et al., (2018) highlighted the increasing importance of microalgae for agriculture and animal feed (Saadaoui, et al., 2021).

Figure 2 provides a simplified process flow diagram for the circular movement of nutrients resulting from phycoremediation. Green microalgae are introduced into the domestic wastewater whereby it improves the domestic effluent through the uptake of nutrients (nitrates and phosphates) from the wastewater. The improved domestic wastewater effluent is subsequently used for irrigation of agricultural crops (pending general and special effluent and reuse standards). Simultaneously, the green microalgae biomass cultivated in the domestic wastewater can be harvested and subsequently (pending quality, quantity, and a risk assessment) be used for products such as biofertilizer or animal feed. In turn, the nutrients from the crops produced or animals that were fed, would again reach domestic wastewater via agricultural waste and surface waters.

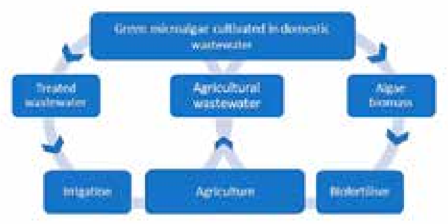


FIGURE 2

Figure 2: A simplified process flow diagram showing the circular movement of nutrients resulting from phycoremediation of domestic wastewater.

The use of phycoremediation as treatment method is gradually increasing globally (Sivasubramanian, 2016; Priyadharshini et al., 2021) but are often implemented as highly technically advanced treatment facilities with controlled environments and dedicated, specifically designed and built infrastructure, such as the high-rate algal ponds (Van der Merwe and Brink, 2018). Back in 1996 already, the Belmont Valley WWTW in Grahamstown, South Africa first introduced phycoremediation in combination with wastewater treatment in what is known as an integrated algae pond system (IAPS) (Momba et al., 2014). This system has been operating for several years and while also incorporated with the wastewater treatment, it makes use of much more technical advances and dedicated infrastructure (Momba et al., 2014).

For the current study, phycoremediation was instead acknowledged and implemented with the main aim to: 1) introduce a self-sustaining system that could operate within the existing municipal wastewater infrastructure, 2) would be cost-effective to implement and maintain, 3) would increase the lifespan of the existing waste stabilisation pond system in rural areas, 4) needed to operate without any electricity, and 5) to improve ecosystem services by removing some of the nutrients (nitrates and phosphates) responsible for widespread eutrophication in the surface waters of our country.

Phycoremediation was first implemented at Motetema WWTW in the Sekhukhune District of Limpopo Province of South Africa in 2016 (Engineering News, 2016; Oberholster et al., 2017) and thereafter in 2017 at Brandwacht WWTW in the Western Cape Province (Mossel Bay Advertiser, 2018; Oberholster et al., 2021). Phycoremediation was implemented as part of the daily operation of these waste stabilisation pond wastewater treatment systems in South Africa, making use of existing infrastructure.

The aim of this paper is to 1) describe the phycoremediation process that has been implemented at the Brandwacht WWTW in the Western Cape, 2) explain the main findings of the research done to date in relation to closing the nutrient loop, and 3) to highlight the main barriers and learning associated with implementing the phycoremediation technology at domestic wastewater treatment plants in South Africa, as these are often not discussed in literature.

2.0 Methodology

2.1 Study site

Brandwacht is a small rural community close to the towns of Friemersheim and Great Brak within the Garden Route District of the Western Cape Province of South Africa. The Brandwacht community consists of 1 470 people living in 398 houses. Just under half of the community have access to safe piped drinking water. More than 88% of the community have access to flush toilets and 96.7% have electricity. Only 1.8% of the community has a tertiary education (Stats SA, 2017).

Phycoremediation has been implemented as part of the everyday treatment and operation at the Brandwacht wastewater treatment works (WWTW) since March 2017. Brandwacht WWTW (34.0493°S and 22.0573°E) is categorised as a micro-sized treatment works as it treats up to 0.5 Mℓ of domestic wastewater daily. The Brandwacht WWTW consists of 7 gravity-fed ponds and is managed by the Mossel Bay local municipality (Figure 3).

FIGURE 3

[Figure 3: Location map of Brandwacht Wastewater Treatment Works in Brandwag. The WWTW is managed by the Mossel Bay local municipality. The Google Earth image of the Brandwacht WWTW shows the 7 ponds and indicates the three bioreactor tanks (1- 3) as well as the pipeline to dose Pond 3 – Pond 6 with algae.

2.2. Phycoremediation technology implementation

2.2.1 Algae selection

Following a literature review (Barros, et al., 2015; Martínez, 2016; Zhu et al., 2018) and laboratory scale studies (Oberholster et al., 2017; Oberholster et al., 2021), it was found that a consortium of the microalgae *Chlorella protothecoides* and *Chlorella vulgaris* (Figure 4) had (1) the potential to take up maximum phosphates (b) the fastest exponential growth rates, and (c) can grow at the largest temperature range. The latter species were mass cultured and inoculated at the wastewater treatment works as part of the field study. Before and after introduction of these cultured microalgae species at the wastewater treatment works, natural algal species were closely evaluated and changes after inoculation, monitored (Oberholster et al., 2017; Oberholster et al., 2021).

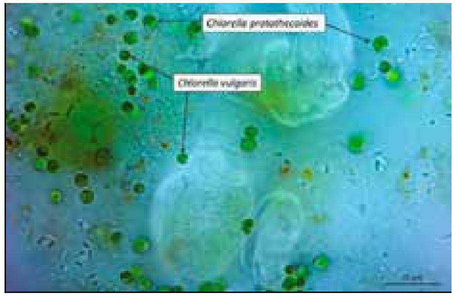


FIGURE 4

Figure 4: Microscope image (600X magnification) of the inoculated algae, ***Chlorella protothecoides*** **and** ***Chlorella vulgaris*****.**

Oberholster et al. (2021) recently published the changes in the algae assemblages before and one year after mass inoculation of the selected algae consortium at Brandwacht WWTW. The dominant natural algae before introducing the consortium of algae to the final effluent pond at Brandwacht changed from *Microcystis aeruginosa* (40%) and *Micractinium pussillum* (24%) to *Clorellaprotothecoides* (52%) and *Chlorella vulgaris* (36%). Continuous dosing of the maturation ponds waste ponds with the cultivated microalgae, allowed the *Chlorella* spp. to dominate and become a self-sustaining system, outcompeting some of the natural species.

2.2.2. Climatic conditions

Serra-Maia et al. (2016) reported optimum growth temperatures for *C. vulgaris* between 20°C and 28°C in bioreactors, while Fei et al. (2015) observed maximum biomass and lipid production by *C. protothecoides* at 25°C. Growth of both species is however significantly inhibited at 35°C. Climate data (average rainfall, humidity, cloud cover, UV index and temperatures) are summarised for the 2017 study period for Brandwacht WWTW, Mossel Bay (Figure 5). Oberholster et al (2021) recently discussed the impact of the minimum air temperatures of 11°C at Brandwacht (Figure 5A) from June to August as below optimum for the microalgae and that a reduction in algae growth and subsequent biomass could be expected. Huisman et al (2002) reported *C. vulgaris* to have a lower light intensity, therefore not requiring a lot of light to grow. Similarly, Brandt (2015) found *Chlorella* a good competitor and an ideal species for cultivation in lower light locations. The cloudy days in the study area are therefore less likely to impact the algae growth than the temperature changes. As explained in Oberholster et al. (2021), the constantly lower temperatures during the colder winter months, required a change from a 4-week cultivation (Figure 6A) to a 5-week growth period in order reach the required chlorophyll-a level (250 mg L^{-1}) and corresponding rich green colour on our simplified algae readiness chart 1 (Figure 6B). Release of the algae at this concentration, as well as weekly manual mixing of the algae in the bioreactors, prevent overshadowing and suspension in the reactor tanks.

FIGURE 5

Figure 5: Climate conditions during 2017 in Mossel Bay. (A) shows the temperature ranges, (B) indicates the average UV index, (C) summarises the % cloud cover as well as the humidity, while (D) depicts the average rainfall (mm) and rainy days. (Source: Weather data obtained from https://www.worldweatheronline.com/)

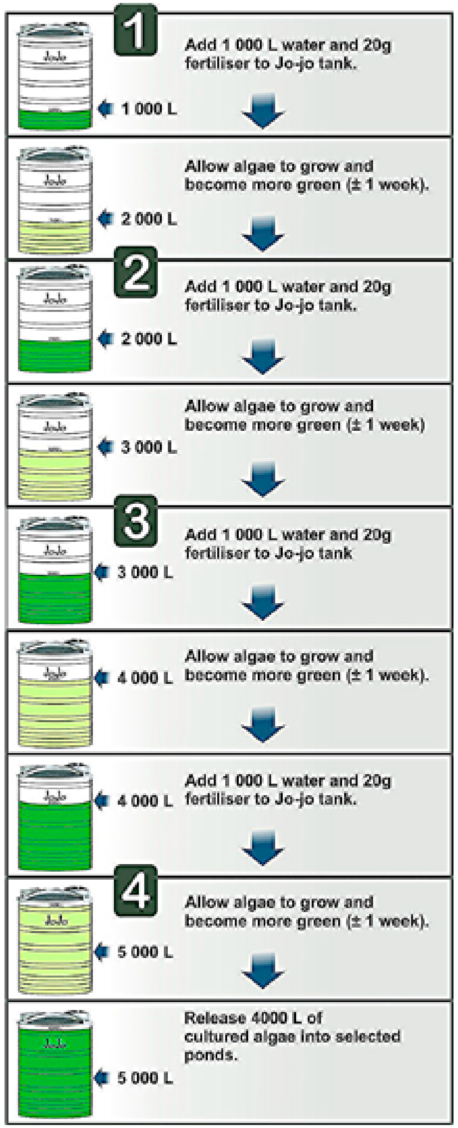
2.3 Water Quality Sampling and Analyses

2.3.1 Physicochemical Analyses

Random water samples were taken before (n=2) and after (n=3) the phycoremediation treatment was implemented at the Brandwacht WWTW as described in Oberholster et al. (2021). The physicochemical water quality analyses of the final effluent (Pond 7) were performed by the accredited water analytical laboratory of the CSIR in Stellenbosch. Analyses were done by means of approved analytical methods detailed in the “Standard Methods for the Analysis of Water and Wastewater” (APHA, AWWA, and WPCF, 1992).

2.3.2 Microbiological Analyses

Microbiological water quality analyses of the water were performed monthly over 6 months (including Summer and Winter conditions) after implementing the phycoremediation technology. Water samples were collected and transported on ice to the CSIR Stellenbosch microbiology laboratory for analyses within 6hrs after sampling. The Colilert-18/Quanti-Tray method for simultaneously detecting total coliforms and *Escherichia coli* (*E. coli*) in water, was employed to determine the log reduction of *E. coli* at each outlet of the 7 Ponds of the Brandwacht WWTW. The *E. coli* count of the final effluent was compared to the Department of Water Affairs and Forestry (DWAF) general and special authorisation standards for discharge of wastewater effluent to a water source (DWAF, 1999), as well as the DWAF (1996) agricultural irrigation guideline for wastewater effluent.



Add 1 000 L water and 20g fertiliser to Jo-jo tank.

Allow algae to grow and become more green (± 1 week).

Add 1 000 L water and 20g fertiliser to Jo-jo tank.

Allow algae to grow and become more green (± 1 week)

Add 1 000 L water and 20g fertiliser to Jo-jo tank

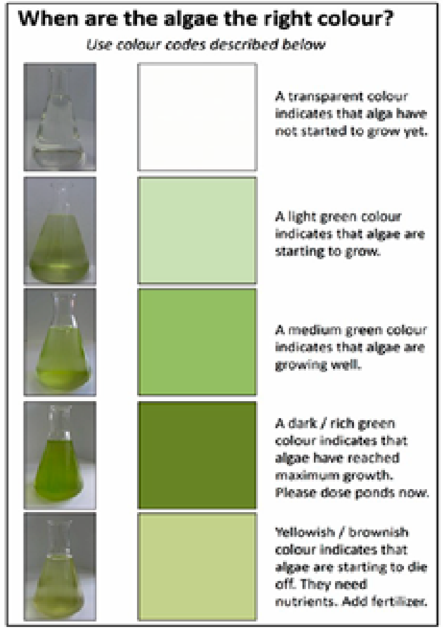
Allow algae to grow and become more green (± 1 week).

Add 1 000 L water and 20g fertiliser to Jo-jo tank.

Allow algae to grow and become more green (± 1 week).

Release 4000 L of cultured algae into selected ponds.

FIGURE 6



When are the algae the right colour?

Use colour codes described below

A transparent colour indicates that alga have not started to grow yet.

A light green colour indicates that algae are starting to grow.

A medium green colour indicates that algae are growing well.

A dark / rich green colour indicates that algae have reached maximum growth. Please dose ponds now.

Yellowish / brownish colour indicates that algae are starting to die off. They need nutrients. Add fertilizer.

FIGURE 6B

Figure 6: Cultivation process of green microalgae (A) over a 4-week period is shown and (B) algae readiness colour chart. The algae are cultivated in 3 – 5 bioreactors (each 5000L in size). Every week, 20gram fertiliser is added with every 1000L water added to each bioreactor tank. The colour chart (B) allows un-trained or semi-skilled plant operators or maintenance staff to understand the algae readiness level for dosing of the waste ponds.

2.3.3 Statistical Analyses

Water quality data were captured in Microsoft Excel Spreadsheets. Simple error bar graphs for the water quality parameters were created in SigmaPlot (Version 14), and statistical analysis was performed using SigmaStat 14. The Mann–Whitney Rank Sum test was used to determine statistical significance for each parameter in the final effluent (Pond 7) of the Brandwacht WWTW. Where data was normally distributed, the Students’ t-test was performed to determine significance. In all tests, the level of significance was adopted at $p < 0.05$.

2.4 Algae Biomass Harvesting

Following a laboratory assessment on the harvesting of algae biomass from Brandwacht WWTW (Van den Berg et al., 2020), a field assessment was done to test biomass harvesting at pilot scale. A small-scale pilot plant (Figure 7) was installed to test the potential removal and harvesting of the algal biomass for beneficiation, while considering costs and potential future upscaling to derive benefits from the biomass for job creation. The volume of biomass that can be harvested from the ponds, depends on various factors (e.g., climate, size of WWTW), and largely decides the feasibility of beneficiation and potential product development.

FIGURE 7

Figure 7: Pilot plant to harvest algae biomass at Brandwacht WWTW. The upper volume of water was pumped from the waste pond to the pilot plant to flocculate and harvest the algae.

To harvest the algae biomass, flocculation is needed and depending on the end-product and to increase the shelf life of the product, drying of the biomass might be required (Viswanathan et al., 2011). For the paper, Zetag 7557 (provided BASF, Germany), a commercially available synthetic cationic polymer was used as it is currently used by the Mossel Bay local municipality in their day-to-day water treatment activities. Pugazhendhi et al. (2019) recorded a 98% removal efficiency of algae from marine water with this product.

For the current study, Zetag 7557 was mixed with the water as it was pumped from the final oxidation pond into the water troughs (200 L) (Figure 7) to a final concentration of 20ppm (optimal concentration according to Lam et al., 2015). Once flocs formed at the surface, sieves were used to manually collect the algae biomass and allow the excess water to drain.

3.0 Results and discussion

3.1 Water Quality

Figure 8 summarises the physicochemical water quality of the final oxidation pond effluent. It highlights the removal efficiencies of the different parameters before phycoremediation and one year after phycoremediation treatment at Brandwacht WWTW. Phycoremediation resulted in an increase in the pH of the final effluent. Acien et al. (2016) cautions that high pH values can impact the performance and growth of both bacteria and microalgae, thereby impacting their capacity to remove contaminants from the wastewater. The pH increase at Brandwacht was in line with what has been described in literature as it relates to CO_2 depletion with increased growth of the algae (Al-Jabri et al., 2021).

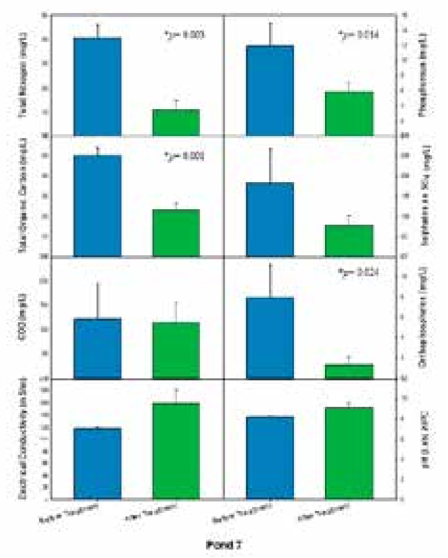


FIGURE 8

Figure 8: Water quality of Pond 7 before and after phycoremediation. Significantly different results indicated (*p< 0.05).

In a controlled laboratory assessment, Singh et al., (2017) recorded rates of up to 87.9% and 98.4% for total nitrogen and total phosphorous removal by C. vulgaris. During field trials, Rao et al (2011) found that nitrites and nitrates were reduced by ***C. vulgaris*** by 48% and 24% respectively, while a 99% phosphate reduction was achieved in high-rate algal ponds. At Brandwacht, the reduction in total nitrate (73.1% removal) and total phosphorous (50% removal) was significantly different before and after the phycoremediation treatment. These results contrasted with what we found at the first pilot plant in Limpopo (Oberholster et al (2017) where 74.4% of the total phosphorous were removed and only 35.4% of the total nitrogen. Oberholster et al (2021) reported much less cloudy days and warmer temperatures at Motetema. Motetema also had far larger total nitrogen concentrations to start with compared to total phosphorous concentrations. Acien et al (2016) stated the importance of the N/P ratio in wastewater as excess nitrogen cannot be removed if phosphorous content is insufficient to allow such removal. The N:P ratio at Brandwach WWTW was 3.4:1 before and 1.8:1 after treatment respectively (Oberholster et al., 2021). There was an increase in electrical conductivity after treatment, exceeding the South African effluent discharge standards of 150 mg L^{-1}. Even though COD levels were reduced by 6.6% from 122 mg L^{-1} to 114 mg L^{-1}, Oberholster et al (2021) noted that the COD still did not meet the South African effluent discharge standard (75 mg L^{-1}) after treatment.

The removal of microbial pathogens from domestic wastewater by means of phycoremediation has been described in literature (Rath, 2012; Emparan et al., 2019; Koul et al., 2021). The microbiological water quality in terms of log ***E. coli*** numbers in the effluent of each of the 7 ponds at Brandwacht WWTW is depicted in Figure 9. From the inlet of raw sewage (*E. coli* = ~6.84 x 106) to Pond 1 to the final effluent of Pond 7 (*E. coli* = ~69), there is more than a 5-log reduction in *E. coli* numbers. Prior to implementing the phycoremediation treatment technology, the Brandwacht WWTW already achieved the DWAF General Standard (red line at 1000 ***E. coli***/100mL) for effluent discharge into a water source. Since implementation however, a further two log reduction was seen from Pond 3 onwards and improved water quality was achieved earlier on in the treatment process. The microbiological quality of the final effluent is such that it can be used for irrigation of sports fields or specific crops (DWAF, 1996). The phycoremediation technology therefore contributed to improved microbiological water quality of the effluent and improved the potential for reuse of the effluent. The phycoremediation technology did not improve the microbiological water quality to that of the target water quality range (0 ***E. coli***/100mL) or special standard (DWAF, 1999) for unlimited reuse and irrigation (DWAF, 1996) indicated by the blue line.

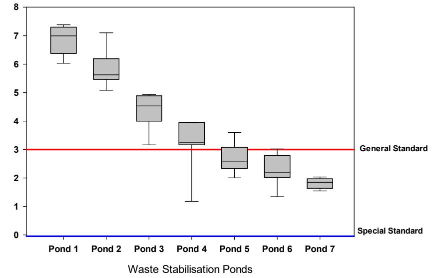


FIGURE 9

Figure 9: Log reduction of *E. coli* and compliance to DWAF effluent discharge standards (DWAF, 1999).

3.2 Biomass harvesting

Barros et al. (2015) reviewed some of the main advantages and disadvantages of the technologies available to harvest microalgae. Flocculation, depending on the flocculant used, adds to the cost and can also be toxic to the end-product or final effluent thereby limiting its re-use (Branyikova et al., 2018; Zhu et al., 2018). Chemical flocculation by means of Zetag 7557 was performed under field conditions. The algae started forming large flocs on the surface of the water troughs within 5 minutes of contact with wastewater (Figure 10).

Wang et al. (2010) reported that microalgae biomass concentrations are usually low (range of 0.5–3.0 g L^{-1}), because of light limitations. This, together with the small cell size of microalgae, renders biomass harvesting costly and energy consuming. Low microalgae biomass concentrations of 0.5 g L^{-1} were associated with open pond reactors, while photobioreactors could have concentrations up to 5g L^{-1} (Vandamme et al., 2013). Few studies reported in-field results from open ponds only using flocculation. Ghayala and Padayaa (2013) reported microalgae concentrations of 10 mg L^{-1} (day 7) after growing microalgae in 10 L bioreactors, making use of centrifugation during harvesting. A total mass of 625mg +/- 50mg of wet algae biomass was collected from every 1000 L of wastewater at Brandwacht. However, this was the results of the first trial and should be repeated, possibly under summer conditions. In-field trials of different flocculants or other harvesting methods should be investigated.

FIGURE 10

Figure 10 Photos of the in-field flocculation and harvesting of algae biomass at Brandwacht WWTW.

3.3 Barriers to phycoremediation at the pilot sites

Increasingly, phycoremediation is successfully implemented to remove pollutants from wastewater, while simultaneously harvesting beneficial biomass for various end-products. The advantages of phycoremediation and closing the nutrient loop is clear and well documented in literature (Rao et al., 2011; Renuka, et al., 2020). The technology can be implemented as a low cost, green solution that does not require high energy or an additional carbon source (Whitton et al., 2015; Oberholster et al., 2019). In fact, the algae use CO_2 as its carbon source, which has further positive impacts for sustainability with regards to reduction in greenhouse gas emissions (Ghayala and Pandyaa, 2013; Singh et al., 2019). However, the success of the phycoremediation technology is directly linked to various aspects such as microalgae selection, closed versus open culture systems, climate-related aspects, as well as harvesting techniques ((Whitton et al., 2015; Koul et al., 2021).

Climate variations can negatively impact the growth rate of the selected microalgae and overall performance of the treatment making use of open ponds (in our case, existing waste stabilization oxidation ponds), causing delays in system turn-around times as was seen at Brandwacht WWT. The study area frequently experienced >30% cloud cover for 80% of the time which resulted in a changed Winter cultivation framework of 5 weeks instead of 4. Even after careful selection of the microalgae consortium, ***Chlorella vulgaris*** and ***Chlorella protochoides***, for their large biomass potential and wide optimum growth temperature range, low biomass concentrations were retrieved.

Considering the high pH of the water and the temperature fluctuations, as well as the fact that the algae was cultivated in open waste stabilisation ponds, the low microalgae concentrations retrieved is not surprising. Subsequent research showed that the flocculant supplied by the local municipality, is best used in marine waters and might not have retrieved efficient concentrations of the ***Chlorella*** spp. The algae biomass, in contrast to most studies, was not centrifuged nor concentrated, or dried as these costs or infrastructure would not be available to rural municipalities in South Africa. While the technology improved the physicochemical and microbiological water quality, and obtained good nutrient removal efficiencies, the treatment failed to improve the water quality to comply with the South African effluent discharge standards. This limits some of the reuse options in terms of reuse of the water for irrigation and the type of crop (e.g., sports fields or food crops) that could be irrigated. Based on the low microalgae biomass concentration harvested, feasibility of the technology and further initiatives to improve the low-cost system, should be investigated. The costs and need for solar-/ wind turbines connected to a mixer in the bioreactor or the addition of an extra bioreactor to increase algae cultivation and subsequent biomass, should be interrogated. This might assist in improving the effluent quality to within the guideline limits. Harvesting of the algae biomass requires further research in terms of flocculant and harvesting technique. The environmental impact of the flocculant used for harvesting algae biomass should be carefully selected based on the end-product envisaged.

4.0 Conclusion

Even though large-scale production of microalgae is an emerging technology, it shows great advantages, also for rural areas of developing countries. Domestic wastewater of improved quality could be obtained at very low cost, reducing the selling prices of irrigation water for agricultural production. Harvested biomass can be exploited as algal bio-fertilizer in African countries with an agriculture dominant sector. With the nutrient recovery by microalgae growth, potential pollution of the wastewater can be dramatically reduced to prevent eutrophication in waterbodies. There are however several barriers and disadvantages, especially when trying to keep the costs to the minimum. Cultivation of the microalgae in open waste stabilisation ponds, render them sensitive to climate fluctuations or low biomass concentrations. Cost-effective ways to harvest enough microalgae biomass for producing bio-fertilisers and allow for small scale job creation in developing countries are needed.

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- 1 In some rural areas of South Africa, wastewater treatment plant operators or workers are semi-skilled or do not have the infrastructure to measure the chlorophyll-a level in the tanks. The project team therefore developed a colour chart indicating the algae readiness level for release into the waste ponds.

Photo by Pok Rie from Pexels