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Municipal Waste Water Reclamation to Increase Water Supply in Botswana.

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Background information

Municipal wastewater reclamation offers opportunities to curb the increasing global scarcity of freshwater in water stressed countries like Botswana. Over the past decades, the country has experienced drought years intensified by climate change. The country has sporadic rainfall patterns ranging from a high of 550 mm and low of 200 mm per year, and an estimated annual average evaporation rate of 1400 mm. The bulk of the country west and southwest, is occupied by the Kalahari Desert and only the northern and eastern rim of the country receives significant rainfall amounts for both domestic and agricultural uses. Also, the rain only falls in the summer months of November to April (World Bank, 2017). This has increased pressure for Botswana to seek new fresh-water supply sources in order to meet the increasing water demands due to rapid increase in urbanization and population. Wastewater presents an attractive alternative to the current water resources as it is already available and produced in significant quantities in the country. The use of wastewater to augment potable water resources is not a new approach as it has been used elsewhere in the world (Arévalo *et al.*, 2009; Pedrero *et al.*, 2010). However, the use of wastewater could present public health risks if due care is not practiced. In cases where a decision is made to reclaim wastewater, in order to increase water supply schemes, the selected treatment chain should be robust enough to satisfactorily remove contaminants from the wastewater in order to protect and safeguard human health.

Intensive and extensive wastewater treatment technologies are seen as appropriate responses to provide reclaimed water of acceptable quality. However, contemporary water quality issues involving potable reuse of water have raised concerns regarding the efficiency of the systems in removing emerging pathogens such as antibiotic resistance bacteria, related genes and trace organic chemicals. In the context of this work, the use of constructed wetlands and solar disinfection is explored in the removal of antibiotic resistant genes in wastewater. These are established technologies which have proved to be effective in water treatment and removal of conventional water quality parameters. However, these technologies are not specifically designed to remove antibiotic resistant bacteria and genes (ARG) in wastewater. Even though the presence of anti-resistant bacteria and genes in wastewater is not usually regulated or monitored, it poses a potential health hazard. The presence of ARG in effluent from these treatment chains poses a potential threat of transmission into the environment. The results of this work may be of significance in identifying the degree of public health risks to both humans and animals using reclaimed wastewater.

Overall aims and objectives

To understand the potential of passive wastewater treatment technologies in delivering resilient water reuse with regards to protecting public health in Botswana.

Specific objectives

- To understand the impacts of climate change, population growth, population migration and industrial development on the water resource balances in Botswana and ultimately identify the opportunities and priorities for water reuse (Chapter 2).
- To review the literature and identify existing gaps in knowledge on the impact of wastewater treatment technologies on the removal of ARGs (Chapter 3).
- To investigate the seasonal occurrence and removal performance of antibiotic resistant genes by extensive constructed wetlands (Chapter 4).
- To investigate the relative importance of UV fluence and temperature related mechanisms on the efficacy of solar disinfection with emphasis on the impact of solids in water for reuse (Chapter 5).

Botswana water resources review

Data for Botswana water resources was obtained from Botswana Water Utilities Corporation and the Water Affairs' water accounting reports. In cases where the data could not be found in the country reports, data was obtained from the FAO AQUASTAT database. Local river runoff and river water inflow from adjacent countries was used to determine renewable water resources. Past and future water withdrawals of water resources were calculated from published national data. Water used for public consumption, industrial production, irrigation, mining and water loss due to evaporation were taken into account. The economic activities have been classified according to International Standard Industrial Classification of All Economic Activities (ISIC) Rev 3 that Botswana is currently using. Overall, this piece of work indicates that the impact of climate change in Botswana is uncertain, precisely on the amount of rainfall the country will receive. Rainfall has been declining over the years leading to water supply challenges especially in the south-eastern part of the country. Almost all the global climate change models reviewed predict that Botswana will have an increase in drought frequency and severity, particularly in southern and western Botswana. In south-mid eastern Botswana, part of Limpopo basin, precipitation is likely to decrease but there is a likely increase in flooding, putting infrastructure such as roads and dams at risk. Groundwater recharge is also likely to decline. Future population projections up to 2030 puts Botswana's population at 2.8 million. The estimates are given for two percentages population growth rate and constant per capita water use of eighty litres per day. Estimated water demand projections for 2030 stands at 222 Million Cubic Metre (MCM). The current work estimates the water deficit to be 34 Million Cubic Metre MCM which could be met by the 73 MCM of wastewater estimated to be produced in 2030.

Review of wastewater technologies in the removal of Antibiotic Resistant Genes (ARG)

Literature search was performed using the Scopus, Google Scholar and Science Direct databases. The keywords that were used were advanced water treatment, antibiotic resistant genes, background antibiotic microbial resistance and wastewater treatment. The results indicate that Waste Water Treatment Plants (WWTPs) with conventional treatment processes are not very efficient in ARG removal and are hotspots for ARGs spread. However, advanced wastewater cleaning processes in addition to a conventional wastewater treatment offers improved removal of the ARGs.

Extensive wastewater treatment technologies such as horizontal subsurface flow constructed wetlands (HFCWS) presents a viable treatment method where a 5 log removal of ARGs was achieved. These results support established knowledge that the filtration capacity of horizontal subsurface flow constructed wetlands for bacteria is higher than that of vertical subsurface flow constructed wetlands (Senzia, Mashauri and Mayo, 2003). As a result, the removal efficiency of horizontal subsurface flow constructed wetlands for ARGs had better performance (over 50%) than that of vertical wetlands, especially for sulfonamide resistance genes. The HFCWs were more efficient in removing sul1-carrying bacteria than other types of CWs. For drinking water, the addition of ozonation as an advanced step offered more removal of the ARGs. It appears that UV offers the least protection.

Solar Disinfection (SODIS)

This chapter investigates the relative importance of UV fluence and temperature related mechanisms on the efficacy of solar disinfection with emphasis on the impact of solids in water for reuse. Preliminary results showed complete solar disinfection was reached after 7 hours in deionised water seeded with commercial pure culture while complete disinfection in natural wastewater was reached in 3 hours.

SODIS and UV effectively inactivates E.coli with the increase in temperature over time in real wastewater. The synergistic effect of UV & temperature is again confirmed and is within the conclusions of previous studies (Zhang et al., 2017, Vivar et al., 2017, Nwankwo, Agunwamba and Nnaji, 2019). In the controlled laboratory experiments, total inactivation was not achieved at a fluence of 1000 mW/cm^2, contradictory to the results we obtained in the preliminary study. It was observed that turbidity had a great influence on the inactivation of E.coli across all the experiments. Our results indicate the presence of total coliforms in all the samples that were analysed, predominantly Pseudomonas aeruginosa. All SODIS and purely UV disinfection experiments did not reach complete inactivation across different turbidity values. Interestingly, an increase in the colony forming units per 100ml was generally observed for total coliforms. This phenomenon is observed for temperatures under 50 degrees Celsius.

New insights concerning SODIS indicate preferential removal of specific organisms when operating at temperatures under 50 degrees irrespective of the fluence applied. Ultimately this has revealed the importance of the synergistic impact of UV and temperature on providing broad spectrum disinfection.

Seasonal occurrence and removal performance of antibiotic resistant genes (ARG)

The aim of the part of research was to investigate the seasonal occurrence and removal performance of antibiotic resistant genes by extensive constructed wetlands .The genes which are being analysed are class 1 integrase (intl1), class Aβ-lactamase (blaCTX-M and blaTEM), erythromycin resistance gene (ermB), fluoroquinolone resistance gene(qnrS), sulphonamide resistance gene(sul1 and sul2), tetracycline resistance gene(tet(O)), methicillin resistance gene(mecA) and vancomycin resistance gene(vanA). These genes were selected because they are of medicinal importance. Tet (o) was the only detected in all the samples tested. Other genes were not found in the samples. This work will improve understanding of mechanisms of ARG abundance and or removal as well as inactivation of emerging microbial pollutants by vertical constructed wetlands under different seasons. This will contribute to the setting of maximum permissible limits for antibiotic resistance genes in treated wastewater.

The Pilot Plant

Fig 1: The pilot plant at the Glen Valley WWTP. The effluent from the Glenn Valley Treatment Plant is further treated using a planted vertical subsurface flow constructed wetland.

Vertical flow subsurface constructed wetlands (VFCW) are effective in achieving set limits for conventional parameters. In our pilot plant, dissolved oxygen values were significantly higher in the effluent than in the influent due to the higher oxygenation of the CW bed. This was comparable in agreement to studies conducted elsewhere. The pH remained close to neutrality at all sampling points. The removal of turbidity was also higher in our pilot constructed wetland. High levels of faecal coliforms (5 log copies/100mL) were observed in the influent demonstrating that the effluent from the activated sludge plant did not meet Botswana Bureau of Standards for wastewater BOS 93:2012 which is 3 log copies/100 ml for perennial watercourses. The current data show complete removal of faecal coliforms from the system. These results are inconsistent with other systems operated elsewhere where only 2 log removal of faecal coliforms was achieved using vertical subsurface flow wetlands.

Potential Benefits of the Project

The Sue White Fund has made it possible to investigate the potential to augment the current water supply in Botswana using wastewater treated by vertical sub-surface flow constructed wetlands. Through this work, it was determined that Botswana is susceptible to climate change and hence a strategy to increase water supply is urgently needed. This work has identified wastewater as an attractive alternative to the current water resources. The projected water deficit of 34 MCM for 2030 could be potentially met. The implementation of the strategy by the Botswana government will enable an increase water security and improve the livelihood of communities.

Additionally, the Sue White Fund (SWF) has made it possible to contribute to the world of knowledge on the impact of wastewater treatment technologies on the removal of ARGs. This work has identified horizontal subsurface flow constructed wetlands to be more effective in the removal of ARGs than other wetlands. This knowledge has the potential to encourage the uptake of extensive wastewater treatment technologies in the developing countries such as Botswana as opposed to their often high capital intensive counterparts.

The SWF has availed funds which made it possible to buy consumables needed for antibiotic resistant genes and solar disinfection laboratory work. The results of this part of work have provided new understanding on the different mechanisms involved in the inactivation of indicator bacteria through solar disinfection. Furthermore, this work investigated the efficacy of solar disinfection on the seasonal removal of ARGs. If implemented, the results of this research will not only aid in the increasing of water supply in Botswana but also ensure that public health is protected in doing so. This will ensure the provision of clean water to communities of Botswana.

Constraints

The initial completion times have been affected by the COVID-19 pandemic. The project was supposed to be completed in June 2021 but this is currently not possible. I was not able to collect data during the lockdowns, hence the delay.

Future Work

This project is almost complete. I have most of the data expect the sequencing of the selected genes. This is expected to be complete in the next month before starting to work on the thesis.

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