Cultivating Urban Resilience with Some Lessons for Zimbabwe: A Focus on the Efforts in Nutrient Removal and Recovery Technologies in Sub-Saharan Africa

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Abstract

This article aims to examine the wastewater footprint in Sub-Saharan Africa (SSA), focusing on nutrient removal and recovery technologies and how they can be harnessed to efficacy. The SSA region lags in nutrient removal and recovery technologies with regards to wastewater treatment. This is evidenced by such problems as eutrophication and poor water quality. Such inefficiency is explained by various factors which include financial problems and lack of technological skills and political willpower. Although some countries, such as South Africa and Namibia, have adopted modern technology in the reclamation of water, most of the countries within the region are tied down by obsolete technologies in wastewater treatment for the removal and recovery of nutrients. As such, the most practical technologies which may be adopted are the biological nutrient removal technologies being complemented by constructed wetlands techniques, which is surmised as green infrastructure. Nonetheless, this may be encouraged by North-South cooperation as well as effective public-private partnership initiatives.

Keywords: *wastewater treatment, water reclamation, phosphates, nitrogen, eutrophication*

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INTRODUCTION

Nutrient removal and recovery technologies focus mainly on three nutrients: nitrate, ammonium and phosphate. It is imperative to note that such technologies are evident mainly in wastewater treatment and regeneration. As such, this is a paradigm shift from wastewater treatment to water reuse and resource recovery, an approach that leans towards sustainable development in the presence of scarce resources. By and large, the United Nations World Water Assessment Programme (WWAP, 2017) posits that the technological advances in wastewater treatment over the past decades have presented an opportunity to shift the primary objective of wastewater management from 'treat and dispose' to 're-use, recycle and recover resources'. Subsequently, such technologies in nutrient recovery pave way for business opportunities in a bid for sustainable development (Rao *et al,* 2017). Just like any other innovations and technological advancements, nutrient removal and recovery technologies in wastewater treatment are affected by financial support, socio-political willpower, and technological skills. In this regard, the technological diffusion of such technologies in Sub-Saharan Africa (SSA) is not uniform. As such, this article aims to examine the status, and impact of, wastewater treatment in SSA, particularly focussing on nutrient removal and recovery technologies, to recommend viable options.

BACKGROUND AND CONTEXT

In 2015, global leaders met to pave the way for sustainable development, and their pledges have become to be known as the Sustainable Development Goals (SDGs). The sixth SDG is a pledge to "Ensure availability and sustainable management of water and sanitation for all," (United Nations, 2015). Of interest to this study is Target 6.3: "By 2030 improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe re-use globally (*ibid.*)." This target highlights the need for nutrient removal and recovery in wastewater treatment.

As aforementioned, nutrient removal and recovery is a result of technological advancement. Such technologies are necessitated by the realisation that resources for the well-being and sustainability of human life are scarce. For example, Guerra-Rodríguez *et al (*2020) posit that there is an indicative growth in the number of countries in hydric stress. In this regard, Desmirt *et al (*2015) indicate that on average, wastewater contains 250,000 tonnes of phosphates per year. Conversely, a 2001 study by Swiss analysts revealed that if 100% of all nutrients could be captured in household sewage, nearly 30 million tonnes of nitrogen, five million tonnes of phosphorus and 12 million tonnes of potassium could be recovered globally, and this represents approximately a third of the annual total global demand for fertiliser (World Economic Forum, 2017). Such revelations emphasize the need and necessity for nutrient removal and recovery.

At the international level, there are parameters which guide nutrient removal and recovery and the subsequent water reclamation. For example, according to the Environmental Protection Agency of the United States of America (US EPA, 2012), the re-use of reclaimed water is recommended for agricultural purposes only when the concentration of *Escherichia coli* is below 1 CFU/100 mL. Alternatively, the World Health Organisation (WHO, 2011) stipulates that reclaimed water is safe for re-use as long as the concentration of such microbiological contents is below 1000 CFU/100 mL.

LITERATURE REVIEW

Nutrient removal and recovery technologies have undergone some evolutionary processes. There are notable advances made in treatment technologies since the original development of aerated systems such as the activated sludge and trickling filters during the 1920s (WWAP, 2017). The reduction of eutrophication of water bodies as a result of high nutrient content in the discharge has been due to the need for a drive towards nutrient (*ibid.*). Although aerobic or anaerobic biological degradation is the basic method for wastewater treatment, eutrophication can still be a result of the presence of inorganic compounds such as nitrate, ammonium and phosphate (Madkour *et al,* 2020). For nutrient recovery, it is important to employ microalgal cultures (through technologies such as fungi pelletisation-assisted microalgal cultivation). This is because they use the nutrients for growth and such technologies fall under biological nutrient removal (BNR) technologies.

Nonetheless, immobilisation techniques for the enhancement of such biological treatment of wastewater have been proposed by Gonzalez-Fernández and Ballesteros (2013). Alternatively, Huang *et al (*2020) reveal that ion exchange (IEX) processes are being considered for nutrient removal and recovery in municipal wastewater. In this regard, mesolite, a synthetically produced zeolite, with a high capacity for ammonia adsorption with reported values of 4.6 and 4.9 meq/g, would be used in such processes. Additionally, hybrid ion exchange resins (HAIX) with ferric oxide nanoparticles are more efficient in phosphorous nutrient removal than both chemical precipitation and biological methods (Martin *et al,* 2017). Hence, in SSA technological commitments are necessary for nutrient removal and recovery in wastewater.

The European Union adopted a Circular Economy Plan called "Closing the Loop - a European Union (EU) action plan for the Circular Economy" (EU, 2015). This plan was based on the need for sustainable development inclining towards a green economy. Environmentally friendly technologies, as a strategy for nutrient removal and recovery, are at the centre of the plan (Malila *et al,* 2019). In this vein, among the EU-27, 70% of the phosphorus in sewage sludge and biodegradable solid waste goes unrecovered (Ellen MacArthur Foundation *et al*, 2015). Inversely, an increase in the organic waste collection could meaningfully expand the recovery of nutrients (World Economic Forum, 2017). Netherlands presents an effective case study of nutrient recovery (WWAP, 2017). The success has been enabled by a public-private partnership.

In the United States of America (USA), both the government and private entities promote sustainable nutrient removal and recovery technologies through the State Revolving Fund (*ibid.*). The USA uses advanced technologies in nutrient removal and water reclamation to cover for water scarcity. One success story of direct potable re-use of water (DPR) is the Big Spring treatment plant in Texas which uses microfiltration, reverse osmosis and UV disinfection to serve over 250,000 people (WWAP, 2017). The success was enabled by institutions for the detection of chemical and biological contaminants, modern analytical technology and multiple barriers are enforced to ensure safe water for human consumption (Water Environment Federation, 2012). Despite technology, there is also a constructed wetland system which has been also effective and efficient in nutrient removal (National Research Council, 2012).

The adoption of new technologies in nutrient removal and recovery is immensely determined by governmental policies and financial aptitude of the country concerned. For instance, in Japan, innovations in wastewater treatment are fully supported by the government through the Breakthrough by Dynamic Approach in Sewage High Technology (B-DASH) project. The project sought to discover and implement "cutting-edge technologies by subsidizing innovations and standardizing their application" (WWAP, 2017). Japan is also known for harvesting phosphorus from urine with urine-diverting toilets (UNESCAP/ UN-HABITAT/AIT, 2015).

The Case of Egypt

Egypt is mostly an arid country with annual rainfall ranging between 0 and 340 mm (Barcelo´ and Petrovic, 2011). In such climatic conditions, the rainfall is generally insufficient to meet the national water demand. For example, in 2000, there was a lack of freshwater amounting to 14.2 billion cubic metres per year (Ceres and Pacific Institute, 2009). Hence, due to such a situation, the government of Egypt was driven to accommodate water reclamation policies in the agricultural sector, whereby the reclaimed water would be used for irrigation purposes. However, such a policy stance is sometimes marred by an unclear delineation of responsibilities among the relevant authorities. For instance, the wastewater management in Egypt is uncoordinated and cumbersome as seven ministries are involved (Barcelo´ and Petrovic, 2011). Such overlapping of responsibilities leads to duplication of policies and action plans which may pull down the efforts towards achieving the central goal of wastewater management.

Most of the nutrient removal and recovery technologies in Egypt are characterised by a lack of innovation as the technologies are mostly inefficient and overloaded "activated sludge and trickling filter systems" (Fahmy, 2009). Although there are over 200 wastewater treatment plants in Egypt, their distribution is not even between the rural and urban areas such that the overall effect would be serious incidences of water pollution as raw wastewater would be discharged into the same waterways by the rural populations (Abdel-Gawad, 2008).

Most wastewater treatment plants in Egypt are overloaded due to rapid urbanisation and illegal discharge of wastewater with limited or no treatment by some industries into natural water bodies (Barcelo´ and Petrovic, 2011). Alternatively, due to institutional discord, the quality of treated wastewater differs from one treatment station to another, depending on such factors as inflow quality, treatment level, and plant operation efficiency (*ibid.*).

RESEARCH METHODOLOGY

The study employed a desktop research methodology for collating the needed information for the study. In this context, the researcher made use of secondary data whereby governmental reports, journal articles and online publications were studied. Subsequently, the methodology made the research a success since it allowed for a relatively quick gathering of information within a short period. As such, the reliability and authenticity of the information used in the study were guaranteed by the cumulative gathering of information from various sources.

RESULTS

In terms of nutrient removal and recovery, SSA portrays a gloomy picture (Wang *et al,* 2014). Loss of nutrients in African cities can also be explained by unregulated waste input, power outages, increasing wastewater flow rates, high energy costs and lack of re-investments (Nikiema *et al,* 2013). Some initiatives towards nutrient removal and recovery in some of the cities in the region include resource-efficient and cleaner production (RECP) at Musoma Textile Mills Tanzania Limited (MUTEX). MUTEX had some notable benefits which include the following: resource recovery (caustic soda);

enhanced energy and water efficiency; reduction of emissions, solid waste and wastewater; and improved occupational health and safety conditions (WWAP, 2017).

Namibia

The country suffers from chronic droughts, together with rapid urbanisation, and, therefore, the country is described to be under hydric stress (Guerra-Rodríguez *et al,* 2020). The establishment of the second largest water reclamation plant in the world in Windhoek (after the Montebello Forebay, California in 1962) was driven mainly by these two forces. Menge (2006) points out that this new plant "incorporates a substantial technological upgrade". Specifically, the treatment technology is complex, involving a series of filtration (including several membrane stages) and ozonation stages (Veolia, 2018).

Success in wastewater reclamation in Namibia is a result of national prioritisation of water reuse supported by solid governmental strategies (Lefebvre, 2018; Guerra-Rodríguez *et al,* 2020)). Noteworthy is the fact that the New Goreangab Reclamation Plant (NGRP) is another success story for public-private partnerships (PPPs) in Africa as two private companies, Veolia and VATechWabag, are involved (Veolia, 2018). By and large, direct potable reclamation (DPR) requires the most rigorous water quality monitoring to eliminate any risks the public health and to meet strict water quality requirements (WWAP, 2017). An advanced multi-barrier treatment approach is among the factors which influenced such a success (Lahnsteiner *et al,* 2013).

Besides the wastewater reclamation plants, Namibia has also established nutrient removal and recovery plants that complement the two Goreangab treatment facilities. Domestic and industrial effluents are treated separately in the country (Menge, 2006). For example, in Windhoek, the Gammams wastewater treatment plant (GWTP) and the Otjomuize wastewater treatment plant (OWTP) are two biological nutrient removal plants that were established for the treatment of domestic wastes. These two plants employ biological technologies for the removal and recovery of nutrients. Specifically, the GWTP technologies consist of the following: stream biofilters with secondary settling and three maturation ponds; and a second stream which consists of biological nutrient removal activated sludge plant (UCT or modified Johannesburg or Ludzack-Ettinger configuration) and eight maturation ponds (Menge, *ibid.*).

ETHIOPIA

The level of wastewater management in Ethiopia is low and this is attributed to a general lack of sanitation infrastructure, skill, and knowledge of wastewater treatment (Alemu *et al,* 2018). However, this is a portrayal of most African cities (Angassa *et al,* 2017). The country experiences rapid urbanisation with 20% of its population (over 94 million) living in urban areas (Frade, 2019). Interestingly, the country's Ministry of Water Irrigation and Energy (MoWIE) revealed that only 7.3% of all sewage generated in the country's capital city, Addis Ababa, undergoes secondary treatment level, and this has caused serious wastewater pollution problems due to inefficient nutrient removal and recovery technologies Ethopian (MoWIE, 2015; Renuka *et al,* 2015). However, one hiccup for the efficient removal and recovery of nutrients in Ethiopia is financially oriented: the conventional technologies of treatment facilities are not affordable due to a lack of high energy demand, technical expertise and high capital cost (Wang *et al,* 2014; Sankaranarayan and Charles, 2017).

However, the second Growth Transformation Plan of the country, which stretched from 2015/16 to 2019/20, reflects that the country does not have adequate and efficient wastewater systems. However, the government of Ethiopia adopted decentralised wastewater treatment (DWT) technologies in 15 newly built condominiums and these proved to be successful in addressing the lack of sanitation infrastructure capacity to service the growing population in Addis Ababa (Sankaranarayan and Charles, 2017).

The common nutrient removal and recovery technologies in Ethiopia are mostly simple activated sludge technologies (*ibid.*). For example, the Akaki-Kaliti wastewater treatment facility, south of Addis Ababa, consists of two series of ponds, each consisting of one facultative pond, one maturation pond, and two polishing ponds (Alemu *et al,* 2020). However, it was discovered that the physico-chemical quality of the wastewater after primary sedimentation encourages eutrophication (Alemu *et al*, 2018; Angassa *et al,* 2017). Using indigenous algae-bacteria, such as *Chlorophyceae* algae *Chlamydomonas*, *Chlorella*, and *Scenedesmus*, is appropriate for the remediation and efficient reduction of biochemical oxygen demand (BOD_5), and chemical oxygen demand (COD) in municipal wastewater under high-rate algal ponds (HRAPs) conditions (Alemu *et al,* 2018).

Constructed wetlands (CWs) are common and convenient methods of nutrient removal and recovery in Ethiopia. Constructed wetland technology is sustainable in the removal of nutrients and is a feasible solution for wastewater treatment, both economically and technically, if it is well-designed and implemented (Gikas and Tsihrintzis, 2014; Angassa *et al,* 2017). However, the ability to assimilate nitrogen, a vital nutrient for plant growth, is different among macrophyte (Angassa *et al,* 2017). The most common macrophyte used for wastewater treatment in Ethiopia is the Phragmite karka (Tadesse *et al,* 2016). As such, Angassa *et al, (*2017) carried out research to compare the nutrient removal capacity of planted *Vetiveriazizanioide* and *Phragmite karka*. Notable is the observation that the efficiency of planted macrophytes in nutrient removal was more enhanced under the condition that they were planted.

South Africa

Nutrient removal and recovery technologies in wastewater are not explicitly guided by legal instruments in South Africa. Only brief and vague references can be seen only in the following Acts: Water Services Act of 1997; and the National Water Act of 1998, 37(1) (Guerra-Rodríguez *et al*, 2020). As such, only the DNHPD Guide Report No. 11/2/5/3, 1978, is clearer whereby some guidelines for the permissible utilization and disposal of treated sewage effluent are discussed (Guerra-Rodríguez *et al*, 2020). By and large, the WWAP (2017) concurs that in the SADC sub-region, Namibia and South Africa provide two good examples of "using wastewater which, when properly treated, can be a safe source of water for drinking and industrial purposes".

At most, the reclaimed water in South Africa is used for industrial purposes. One case is that which concerns ESKOM, the country's main electricity public utility. For the generation of electricity, water is used for the cooling of the thermal plants. Resultantly, such water would accumulate some pollutants, and, therefore, there would be a need for treatment before it is discharged due to its high salinity and the presence of pathogens and chemical additives (WWAP, 2017; Schutte, 2008). In the early 1980s, ESKOM began installing reverse osmosis plants known as blow-down water, for industrial use. One example of such initiatives is the Lethabo Power Station, in Sasolburg which has a total capacity of 12 million litres per day. After its treatment, some of the water is recycled back into the concentrated cooling water system and the other quantity is used as feed water for the ion exchange process.

In South African municipalities, nitrogen and phosphorus recovery technologies are common (WWAP, 2017). Such facilities need human capital complementary efforts. For example, although Pretoria's Daspoort Wastewater Treatment Works plant was constructed between 1913 and 1920, it is still one of the most efficient treatment plants in the Gauteng province due to capacity building initiatives (Water Research Commission, 2018). Moreover, the treatment facility employs technologies such as a BNR activated sludge, and biological filters for liquid processing and DAF thickening, anaerobic digestion and solar drying beds for the production of sludge (*ibid.*).

ZIMBABWE

The nutrient removal and recovery technologies in the country are stagnant and somehow ineffective. The Zimbabwe Water Forum (ZWF, 2013;2) asserts that "almost none of the biological nutrient [removal] (BNR) plants are working" in seven municipalities (Harare, Bulawayo, Kwekwe, Chegutu, Masvingo, Mutare and Chitungwiza) where wastewater treatment studies were carried out. The African Development Bank (AfDB, 2019) observes that the progressive decline in water and sewerage services culminated in a serious outbreak of cholera in the 2018 semi-dry season of September. Harare is serviced by Crowborough plant which uses BNR and trickling filter; the Firle plant which employs the BNR and the trickling filter system; Marlborough treatment plant which uses the waste stabilisation ponds (WSPs); the Donnybrook Waste Plant which also uses the stabilisation ponds; and lastly the Hatcliffe plant which uses an extended aeration system (Nhapi *et al,* 2006).

Treatment plants servicing Harare are overloaded owing to rapid population growth and a halt in the construction of new treatment plants since 1996 (Nhapi *et al,* 2006). Alternatively, the AfDB (2019) reveals that low levels of periodic and routine maintenance over the past two decades have been the main cause of the deterioration in the quality of the basic infrastructure of the country. Nonetheless, ZWF (2013:1) attributes such problems to low tariff structures which "do not meet the costs of operations, maintenance, and expansion of the network to meet growing demand". Mismanagement and divergence of funds and revenues contribute to such infrastructure problems (AfDB, 2019). This applies to the nutrient removal and recovery of the wastewater in the city. For example, Nhapi *et al, (*2006) assert that the BNR effluent from Firle WTP is poor (13.7 10.7 mg/L TN, 1.9 3.4 mg/L TP) owing to recurrent plant breakdowns and poor maintenance. This is clarified by the fact that the government of Zimbabwe stipulated that the nutrient content of semi-treated wastewater to drain into water bodies are 10 mg/L TN and 0.5 mg/L TP (Government of Zimbabwe Statutory Instrument 274 of 2000). Therefore, one effect of such poor wastewater nutrients is eutrophication.

Eutrophication-related problems have been reported in Lake Chivero, and the problems may be traced back to the colonial era (Magadza, 2003). For example, Marimba River, which discharges into the lake, passes through the Crowborough Sewage Treatment Works (CSTW). Notable is the fact that the CSTW has a design capacity of 54 000 $m^3 \cdot d^{-1}$ but was treating about 103 000 $m^3 \cdot d^{-1}$ in December 2001 (Nhapi and Tirivarombo, 2004). Additionally, the plant comprises a BNR system with a capacity of 18 000 $m^3 \cdot d^{-1}$ which discharges into the Marimba River and a trickling filter (TF) system with a capacity of 36 000 $m^3 \cdot d^{-1}$ which discharges final effluent mixed with primary and secondary sludge to pastures. Eutrophication in the lake is inevitable due to inefficient wastewater treatment because of overload.

Wastewater treatment problems affecting Harare and the rest of the country are a result of poor planning and institutional bottlenecks. For example, the

Chitungwiza City wastewater treatment plant was designed for BOD and TSS reduction, with a capacity of some 20 mega litres per day (AfDB, 2019). In line with the national policy on wastewater discharge, the effluent would not have met the nitrogen and phosphorus standards for discharging into Lake Chivero, and, therefore, the effluent was meant to be discharged into the Mufure watershed through effluent pipes. However, due to low pumping capacity and pump failures, the sub-standard effluent ended up being discharged into Lake Chivero and this has exacerbated the water woes of Greater Harare metropolitan area (AfDB, 2019). There is, therefore, a need for adequate planning in wastewater management.

Planning in wastewater management is needed for the delivery of potable water, especially in areas exhibiting hydric stress such as Bulawayo. The AfDB (2015) iterates Harare is faced with frequent severe water shortages as its average annual rainfall is 590mm. The city is the highest beneficiary of donor funds for wastewater treatment in Zimbabwe (ZWF, 2013). However, the AfDB (2015;12) posits that the city's wastewater treatment plants and sewerage services need thorough refurbishment, citing that "of the 80Ml/day expected to be treated, only 30% is finding its way into treatment facilities with 70% being discharged directly into streams and rivers". Ironically, the city envisages water reclamation for potable, drinking, water from such sewerage reservoirs, the Khami Dam specifically.

DISCUSSION

Nutrient removal and recovery technologies are of great significance in sustainable development since they ensure that there is no loss of nutrients, a situation which may disrupt the eco-system through such occurrences as eutrophication (Huang *et al*, 2020). In this regard, besides balancing the nutrient content of the eco-system, nutrient recovery also enables the establishment of other means of wealth creation such as making fertiliser (Sikosana *et al*, 2017). As such, the development of recovery processes for nutrient recycling is gaining increasing attention due to both economic and environmental reasons (Guerra-Rodríguez *et al*, 2020).

The cases under review reflected different stages of adopting the necessary technologies for the removal and recovery of nutrients in wastewater. Namibia and South Africa have been more successful in adopting modern technologies. In Namibia, necessity pushed for the adoption of the needed water reclamation technologies. As such, water scarcity, which is projected to be more common due to climate change, may also be the needed driver for technological advancement in wastewater treatment and reclamation. With regards to South Africa, various factors played a hand in the resuscitation of wastewater. A vibrant economy and political willpower are the major factors that contributed to the country to be recognised as a champion of wastewater reclamation in the SSA region. The adoption of new and modern technologies is initiated and complemented by healthy funding from the government. Therefore, since South Africa's economy is among the fastest growing ones in SSA, the needed funding for research and development in nutrient removal and recovery is available (World Bank, 2010, 2019).

The cases of Ethiopia and Zimbabwe reveal the negative effects of rapid urbanisation on wastewater treatment. As such, due to overpopulation, the existing infrastructure for wastewater treatment becomes overwhelmed, leading to overloading and inefficiency in nutrient removal and recovery. These sentiments are echoed by United Nations Economic Commission for Africa (UNECA, 2016) which points out that the increased generation of waste in SSA is driven by population growth, industrialisation and rising living standards. The cost effective high-rate algal ponds (HRAPs) adopted by both countries are, however, constrained by the need for large tracts of land around the major cities. However, in Ethiopia, decentralisation of treatment plants has been found effective in wastewater treatment.

The economic crisis in most African countries has led to a reliance on biological nutrient removal technologies for wastewater treatment. However, depending on the effectiveness of particular treatment facilities, nitrate, ammonium and phosphate ions would still be present in the partially treated wastewater. Resultantly, most countries in SSA make use of HRAPs for the secondary treatment of the waste-water. African cities have not been able to set up adequate systems for the management of municipal and industrial waste due to poor infrastructure, limited resources and lack of proper urban management systems (UNECA, 2016). This is at the background of the African states lobbying for infrastructural development in the Agenda 2063 blueprint (African Union Commission (AUC), 2015). It is noteworthy that Aspiration 1 of Agenda 2063 was: A prosperous Africa based on inclusive growth and sustainable development and the target of the Aspiration was that "Cities and other settlements are hubs of cultural and economic activities, with modernised infrastructure, and people have access to affordable and decent housing, including housing finance, together with all the basic necessities of life such as water, sanitation, energy, public transport and ICT" (AUC, 2015). However, such developmental aspirations are yet to be realised concerning the quality of water and wastewater treatment in most African countries which were signatories of the endogenous plan for transformation.

One common feature to explain the lag in adopting new technologies in SSA is that the African countries experience economic downturns, and, therefore, the central governments usually fail to inject much needed funds for the renovation and maintenance of wastewater treatment plants (Nikiema *et al,* 2013; Wang *et al,* 2014).

Some SSA countries practise the modern sanitation technique in wastewater treatment (Guerra-Rodríguez *et al,* 2020). This is a systematic approach that aims to recover and, thus, recycle nutrients, such as nitrogen, phosphorous and ammonium through cost-effective technologies. In pursuit of this approach, although there are numerous technologies for recovering nutrients, crystallisation/precipitation is the most popular one for its simultaneous recovery of nitrogen and phosphorous nutrients in the form of struvite (Cie´slik and Konieczka, 2017). However, such technologies are not yet widely adopted in SSA due to a dearth of technological skills and innovation capacities. As such, some countries have adopted sludge valorisation techniques and this way, the nutrients would be recovered through agricultural activities (Laura *et al,* 2020). Nonetheless, sludge valorisation, although it is most evident in developed countries, may be advanced technologically to remove organic pollutants through adsorption processes (Sun *et al,* 2019). By and large, condominium systems are being implemented in several African countries as decentralised microsystems, replacing the conventional centralised treatment systems (World Bank, 2010).

CONCLUSION AND FUTURE DIRECTION

Nutrient removal and recovery technologies in most parts of SSA are still not efficiently developed, as evidenced by the problems of eutrophication associated with wastewater treatment in less economically developed countries such as Zimbabwe. In this regard, there is a need for well-established public-private partnerships in the wastewater treatment facilities. Such initiatives were successful in Namibia and Egypt, as highlighted above. Additionally, North-South cooperation is needed for the necessary transfer and, diffusion, of nutrient removal and recovery technology. This was echoed in the SDGs blueprint whereby it was noted that although governments had a mandate to sustainably develop their own countries, most countries in SSA needed special attention in being assisted by more economically developed countries. As such, there is a need to adopt efficient and affordable technologies environmentally suitable for SSA, as well as investing in research and development for new technology and waste minimisation options in the region.

Moreover, there is a need for a paradigm shift in tackling the problems associated with nutrient recovery in wastewater. Instead of a compartmentalisation mentality in wastewater treatment, the interested stakeholders, the responsible authorities and households included, may need to adopt a systems approach in nutrient removal and recovery. For example, it is well established that nutrients, such as phosphorous are valuable as fertilisers. Therefore, there is a need for households to monitor their wastewater, putting into consideration that it is a valuable resource, as exemplified in Ethiopia. By and large, such initiatives may lead to decentralisation of the wastewater treatment plants, which is cost-effective and more efficient.

As it was established that most countries in the SSA region lack adequate financial means to pursue modern and more efficient nutrient removal and recovery technologies, one option which is less financially demanding but is as effective, is the adoption of "Green infrastructure". This is a euphemism for natural means of nutrient removal and recovery and it includes both natural wetlands and constructed wetlands. The adoption of such technology ensures that wastewater is processed at minimum costs while at the same time promoting the ecosystem. However, as aforementioned, land for such activities may become a constraint.

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