Impact of source-separation of urine on treatment capacity, treatment process, and capital expenditure of a decentralized wastewater treatment plant

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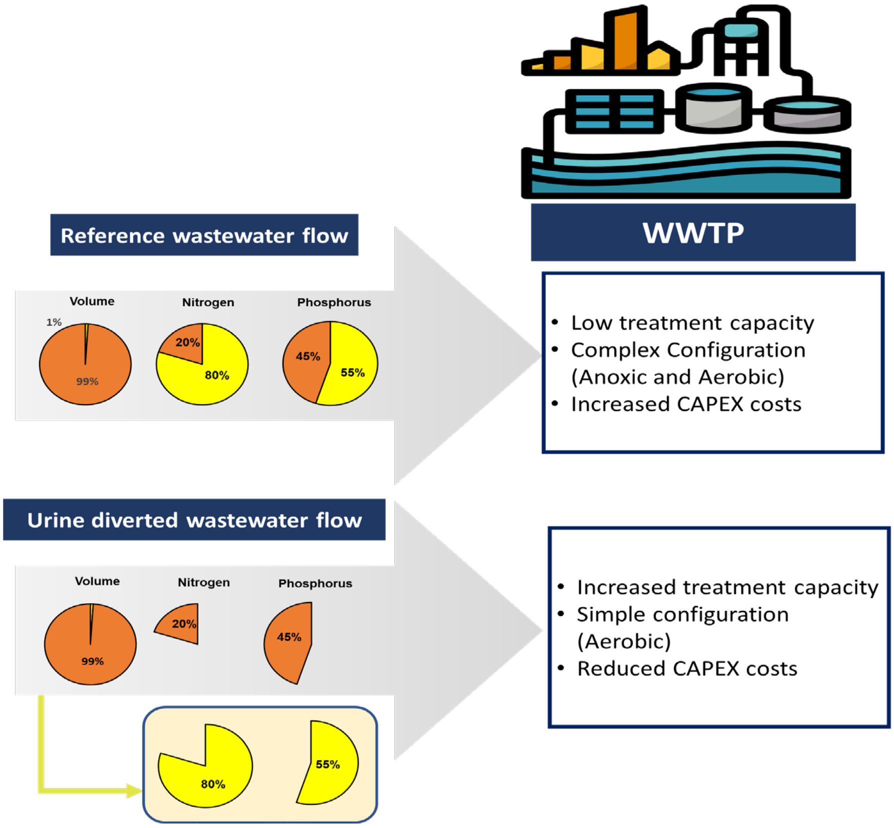
Highlights

- The effects of urine diversion on treatment capacity, process and capitals costs modeled with BioWin
- BioWin modeling revealed that with 75% urine diversion, treatment capacity can be almost doubled
- With 75% or more urine diversion the current complex treatment process can be replaced with a simple aerobic membrane bioreactor (MBR)
- 24% of the current capital costs can be reduced with urine diversion.

Graphical Abstract



Abstract

In this study, the impact of urine diversion on treatment capacity, treatment process, and capital costs of a decentralized wastewater treatment plant (WWTP) was investigated using BioWin software for simulations. The simulations showed that with 75% urine diversion, the treatment capacity of the WWTP can be almost doubled compared to 0% urine diversion although increase was not very significant for urine diversion above 40%. With 75% or more urine diversion, it was found that the current complex treatment process can be replaced with a simple aerobic membrane bioreactor (MBR) to produce the same effluent quality, with significant reduction in the plant footprint. Anaerobic membrane bioreactor followed by adsorption process can also be an alternative process, although further investigations are needed to understand the feasibility of this approach. Replacing the treatment process with a simple aerobic membrane bioreactor can save up to 24% capital costs mostly by reducing the space requirement. Sensitivity analysis revealed that by operating the bioreactor at higher MLSS concentrations (9 g/L instead of 5 g/L) could help increase the WWTP treatment capacity by about 3.5 times at 75% urine diversion. Hence, urine diversion (until nitrogen limiting conditions occur) can increase the treatment capacity of an existing wastewater treatment plant and reduce the capital expenses on space requirement of the treatment plant.

Abbreviations

WWTP, wastewater treatment plant ; MLSS, Mixed liquor suspended solids ; MBR , Membrane Bioreactor ; UV, Ultra Violet ; RO , Reverse Osmosis

Keywords

Treatment Capacity, Source separation of urine, Wastewater treatment plant, Denitrification

1. Introduction

Water is an essential natural resource, which is crucial to life, work, food security, and sustainable economic advancements (Barnett & Morse, 2013; Dorji et al., 2022). However, this resource has come under stress due to growing human population, urbanization and climate change. This demands improved management to safeguard water security and to protect receiving water bodies from environmental pollution (Metcalf et al., 1979). Water security serves different purposes, including protection of environmental flows and consequent support of associated ecosystems, provision of water for drinking and irrigation, and uptake of wastes through abiotic/biotic cycling (Carey & Migliaccio, 2009). Appraisals demonstrate that 60% of the world will live in urban areas by 2030 (Division, 2008). With a growing population size, there is a more prominent freshwater demand, and consequently, increasing volumes of wastewater are produced, particularly in urban areas (Sherbinin et al., 2007). The sustainability of basic water resources, especially in urban areas, relies on efficient wastewater management.

Sydney has been experiencing a rapid population growth rate. The Metro Strategy (2005) anticipates that Sydney's population will continue to grow at an average annual change of 1.85%. The population is about 5.3 million in 2020 and is predicted to reach 7.7 million by 2050. This is expected to increase the volumes of wastewater proportionally. Hence, in the future, it is expected that higher volumes of wastewater will need to be treated by the wastewater treatment plants (Carey & Migliaccio, 2009; Teklehaimanot et al., 2015). Commissioning additional wastewater treatment plants would increase space and volume requirement per unit treatment of wastewater. Availability of space especially in urban areas is limited, and land is expensive and would substantially contribute to capital expenditure (Gurran et al., 2020; James, 2016; Nabarro & Smart, 1978). Hence, alternative ways to treat wastewater that can increase the capacity of the existing wastewater treatment plants without the need of additional land or space are essential.

In a biological wastewater treatment processes, nitrification is often the rate-limiting step that determines the space necessities due to its slow rate and sensitivity to inhibitory factors like temperature, pH and toxic compounds (Henze et al., 2002; Zhou et al., 2020). Inefficient nitrification causes process failure in activated sludge processes by producing higher effluent ammonia and total nitrogen concentration due to the slow growth rates of nitrifiers (Zhou et al., 2020). Besides, low carbon availability in domestic wastewater demands the addition of organic chemicals, and thus increases the operating expenses to enable complete nitrogen removal from wastewater (Sun et al., 2010). Moreover, nitrogen removal requires high energy inputs in the form of aeration (for nitrification) and high recirculation ratios (to enable denitrification). Denitrification step also increases the space and volume requirement of the treatment process. In summary, improving nitrogen removal to levels that are adequate to decrease eutrophication is challenging because of limited land availability, and high capital and operational expenditure. Alternative approaches for nitrogen removal like anammox and ion-exchange to remove nitrogen from side streams have been developed (Ma et al., 2016; Wang et al., 2017). Nitrogen removal by Anammox process is at present applied in more than a hundred full-scale installations for treatment of anaerobic digestion reject water (Lackner et al., 2014; Lotti et al., 2015; Van Hulle et al., 2010). However, mainstream applications of the anammox process face obstacles due to slow growth rate and high sensitivity to low temperature conditions and necessity of a certain influent NO_2^--N/NH_4^+-N ratio (Morales et al., 2015; Tomaszewski et al., 2017). Ion exchange processes to remove nitrogen from wastewater are technically and economically unfeasible (Zhou et al., 2020). Hence, there is a convincing need to develop new technologies for stable and effective nitrogen removal that require less space than the current removal processes.

It has been reported widely that urine contributes approximately 70-80% of the nitrogen, 45-50% of the phosphorus in domestic wastewater, although it makes up only 1% of the overall wastewater volume (Badeti et al., 2021; Maurer et al., 2006; Randall & Naidoo, 2018; Wilsenach & Van Loosdrecht, 2004). Various source separation methodologies (like waterless urinals or no-mix toilets) have been tested which offer a new and simple technique for collecting urine within office blocks and other commercial buildings (Gundlach et al., 2021). Also, reusing of nutrients at the source offers a more economical and natural strategy for fertiliser production since minimal energy is required and waste streams are converted to valuable products (Flanagan & Randall, 2018). Hence, several approaches have been proposed over the years to efficiently recover nutrients from source separated urine (Freguia et al., 2019; Maurer et al., 2006; Udert & Wächter, 2012; Volpin et al., 2020a; Volpin et al., 2020b). In addition, waterless urinals offer an excellent way to save substantial amount of water which is generally consumed for flushing. Simultaneously, the nutrient loads to wastewater treatment plants are significantly reduced by implementing source separation of urine (Almuntashiri et al., 2021; Kvarnström et al., 2006; Vinnerås & Jönsson, 2013). Therefore, urine diversion and its treatment have gained popularity in the past few years and are seen as a possible option towards efficient nutrient recovery and sustainable wastewater management. Previous studies taken by Wilsenach and Van Loosdrecht (2004), Wilsenach and van Loosdrecht (2006), Chipako and Randall (2020), Badeti et al. (2021) and Hilton et al. (2020) to mention few, have shown that urine diversion from wastewater can unlock treatment capacity, reduce effluent nitrogen concentration, and reduce the energy consumption of centralised wastewater treatment plants. In our previous work (Badeti et al., 2021), we have investigated the effect of urine diversion on effluent nitrogen, energy consumption, and greenhouse gas emissions of Sydney Central Park WWTP (a decentralised wastewater treatment plant that involves membrane treatment processes for water reuse). Our findings in the previous work (Badeti et al., 2021) have revealed that 33% of the aeration energy and 25% of the total greenhouse gas emissions could be reduced by diverting about 90% of the urine.

In this work, we have extended our investigations to study the effect of urine diversion on the treatment capacity, treatment process and capital costs of an existing wastewater treatment plant using BioWin modelling software. Recent efforts to change existing wastewater treatment plants to be energy neutral or positive has resulted in the development of anaerobic MBR (usually known as AnMBR). Since aeration is not required, AnMBR consumes less energy than aerobic processes (Liu et al., 2020). Additionally biogas is produced which can be converted to electricity. However, poor nitrogen removal is one of the disadvantages of this process which can add complexities to the post treatment (Dvořák et al., 2016). However, with urine diversion a major portion of nitrogen is diverted at source which avoids the need for nitrogen removal (Badeti et al., 2021). The feasibility of incorporating aerobic MBR and AnMBR processes with urine diversion has been investigated in this study. Most of the treatment plants employ secondary clarifiers or membrane processes to remove MLSS from the biological treatment processes (Henze et al., 2002; Metcalf et al., 1979). MLSS concentration in the bioreactor directly determine the solids loading rate to the secondary clarifier (James et al., 2015) or the membrane fouling propensity in the case of a membrane bioreactor (MBR) (Kawasaki et al., 2011; Schwarz et al., 2006). Hence, operating at a constant MLSS concentration is generally a standard practice for wastewater treatment plants to keep the clarifier in safe operation or reducing MBR membrane fouling propensity. However, another study (Wilsenach & Van Loosdrecht, 2004) showed that operating at a constant MLSS concentrations limits the potential to increase the capacity of a wastewater treatment plant when the urine diversion is increased beyond 40% due to insufficient growth of nitrifying bacteria. MLSS concentration cannot be increased too much to provide sufficient bacterial growth in the bioreactor when clarifiers are used to separate suspended solids. However, in the case of MBR processes, the treatment capacity of the bioreactor can be enhanced by increasing the total membrane area to operate at lower hydraulic retention time (HRT) and increase MLSS concentrations but maintaining similar membrane flux or even at lower flux so that membrane fouling is controlled. Hence, a sensitivity analysis was performed to investigate the treatment capacity when operated at higher MLSS concentrations.

2. Methodology

2.1 Description of the wastewater treatment plant

The WWTP investigated in this study is located in the basement of the Sydney Central Park located at Ultimo, in front of the University of Technology Sydney Ultimo campus. The plant receives mixture of domestic wastewater (from apartments and public toilets) and trade waste from commercial centres (shops and offices). Wastewater produced is treated through biological and membrane treatment processes (including MBR, UV, and RO). A complete description of the treatment processes at Central Park WWTP has been described in our previous submission (Badeti et al., 2021). In our previous study, we have configured these processes (excluding UV and RO) on BioWin modelling platform, calibrated and validated with real data (effluent water quality and energy consumption) of Central Park WWTP. The same model has been used to extend our investigation on the following parameters in this study.

2.2. Treatment Capacity

The potential increases in the treatment capacity of the existing decentralised WWTP (i.e, increased number of people connected from the current capacity of 1.0 MLD) with urine diversion were investigated. The target effluent concentrations include ammonium nitrogen NH_4-N = 1 mgN/L and total nitrogen TN = 7.8 mgN/L from their influent concentrations of NH_4-N = 72 mgN/L and total nitrogen TN = 90 mgN/L (Badeti et al., 2021). The increase in flow rate was determined through iteration. Mixed liquor suspended solids (MLSS) in the reactor was kept constant, and the reference effluent concentration was not exceeded. With increasing influent flows, the SRT was decreased to maintain constant MLSS concentration in the bioreactor. The increase in treatment capacity was compared to the capacity of the reference scenario. The number of people connected was calculated based on the inflow rate (0.15 m^3/d per EP).

2.3. Treatment Processes

Two different treatment processes are proposed in this study with a lesser footprint compared to the reference scenario. These treatment configurations were modelled on BioWin to determine the effluent nitrogen concentrations produced under different urine diversion. The inflow rate (0.434 MLD) and temperature (20°C) were the same for all three scenarios. The brief description and total volume of the treatment process are described in Table 1. The MLSS were maintained at 5000 mg/L in configurations A and B. Since, configuration C was an anaerobic system, the total suspended solids were increased to 10,000 mg/L for configuration C. The fate of nitrogen and effluent nitrogen concentration in both configurations were monitored for various percentages of urine separation. Finally, a comparative economic assessment was conducted for these three different configurations.

Table 1- Different treatment processes compared

Configuration	Description	Total Volume (m^3)
A	Anoxic - Aerobic - Alum - Membrane tank (See Fig 2a)	660
B	Alum - Membrane bioreactor(See Fig 2b)	500
C	Alum - Anaerobic Membrane bioreactor (See Fig 2c)	500

*The effect of urine diversion on configuration A has been investigated in our previous study (Badeti et al., 2021). In this study we have investigated configuration B and C.

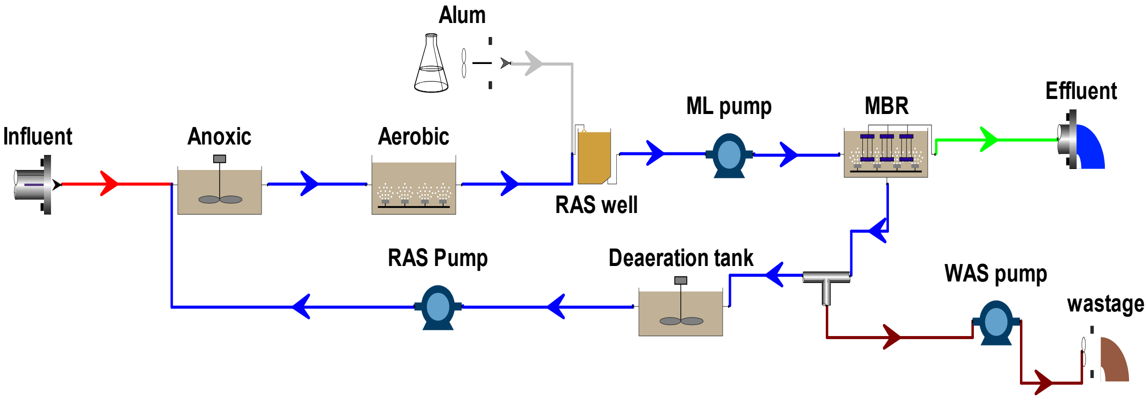


Fig 2(a)

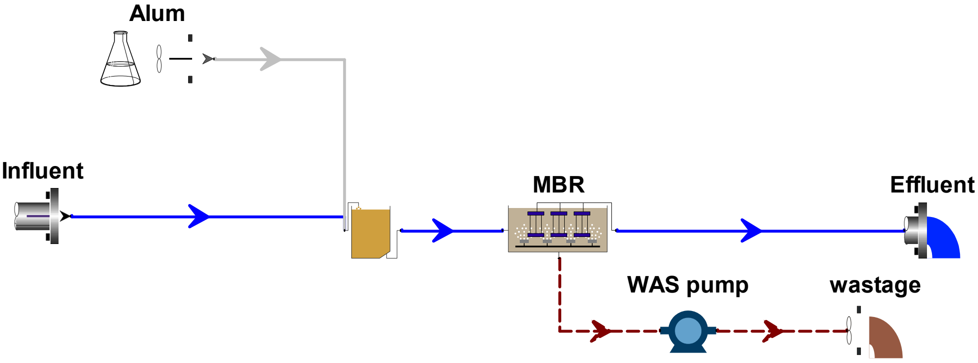


Fig 2(b)

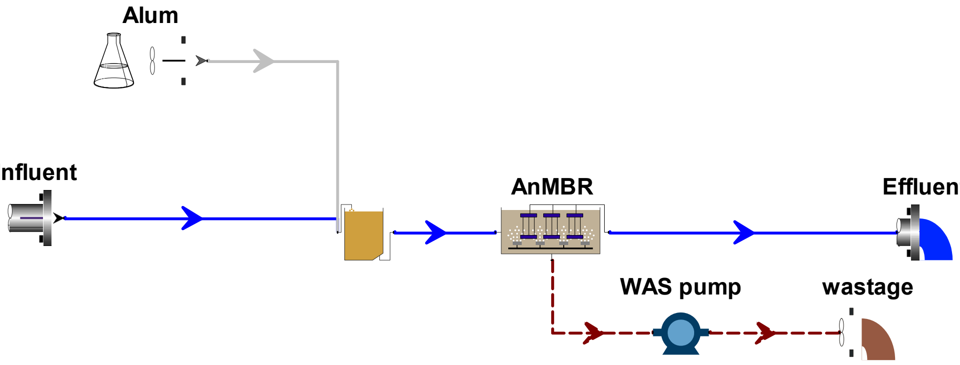


Fig 2(c)

Fig 2 – (a) Schematic of current treatment process at Central Park (b) Schematic diagram of Alum-MBR (c) Alum-AnMBR proposed in this study. These processes are generated by BioWin.

2.4. CAPEX estimations

The CAPEX estimation includes the cost of space and civil works. The cost of commercial space in Central Park was assumed at AU\$1000/m^2/year as provided by the Central Park's asset management office and this value has been used for space cost. The cost of civil work are based on values reported in (East, 2018; Fernández-Álvarez et al., 2014) and it includes costs of process units such as reactors, pumps and membranes. Other components such as the cost of the membrane module, valves, and pipeline have not been included in this study. More details on the cost analysis has been provided in supplementary information. The annualized CAPEX cost (A\$/yr, CAPEXa) was determined at an interest rate of 6% and plant availability of 0.95 for a 20-year plant lifetime (i.e. n). The CAPEXa cost in A\$/yr is therefore calculated based on the following equation:

$$\text{CAPEXa} = ((\text{Total CAPEX cost}) * i * (i + 1)^{n}) / ((1 + i)^{n} - 1) \qquad (1)$$

2.5. Sensitivity Analysis

The potential variations in the treatment capacity of the existing decentralised WWTP (i.e, increased number of people connected) with urine diversion, when operated at various MLSS concentrations were investigated. These effluent concentrations were taken as target values (NH_4 = 1mgN/L and TN = 7.8 mgN/L). The increase in flow rate was determined through iteration. Total suspended solids in the reactor were maintained at 7.5 g/L and 9 g/L, and the reference effluent concentration was not exceeded. With increasing influent flows, the SRT was decreased to maintain constant MLSS. The increase in treatment capacity was compared to the capacity of the reference scenario.

3. Results and Discussions

In this section, the effect of increasing urine diversion rates on the following parameters has been discussed in detail.

3.1. Treatment capacity

Fig. 2 shows the potential increase in treatment capacity with increasing urine diversion at source up to 75%. The treatment capacity for the reference scenario at 20°C was 1MLD (i.e. 6666 population equivalent). For 10% urine diversion the aerobic zone was increased by 100 m^3 (with urine diversion the required anoxic tank volume was reduced and aerobic tank was increased respectively so that total volume (anoxic + aerobic) remained constant), which made a capacity increase of 40% possible. For 45% urine separation and higher, the complete anoxic zone became an aerobic zone. The maximum increase in influent capacity relative to the reference flow rate, with urine separation and increasing the aerobic zone at the expense of the anoxic zone, was 92%. At higher urine separation percentages, the rate of capacity increase with urine separation was relatively small. From 0 to 15% urine separation the treatment capacity was limited by effluent nitrogen concentration. For more than 15% urine separation effluent ammonia was the limiting factor. The decrease in nitrifiers made the maximum allowable ammonium concentration limiting, although the total nitrogen effluent concentration still decreased.

Previously, Wilsenach and Van Loosdrecht (2004) evaluated the effect of urine separation on the treatment capacity of a centralised BCFS (Biological–chemical phosphorus and nitrogen removal) treatment process operated under Dutch climate and working conditions. The authors observed a similar effect on treatment capacity with urine separation. However, the authors observed no further increase in the treatment capacity for urine diversion above 40% due to insufficient growth of nitrifiers which led to higher effluent ammonia concentrations.

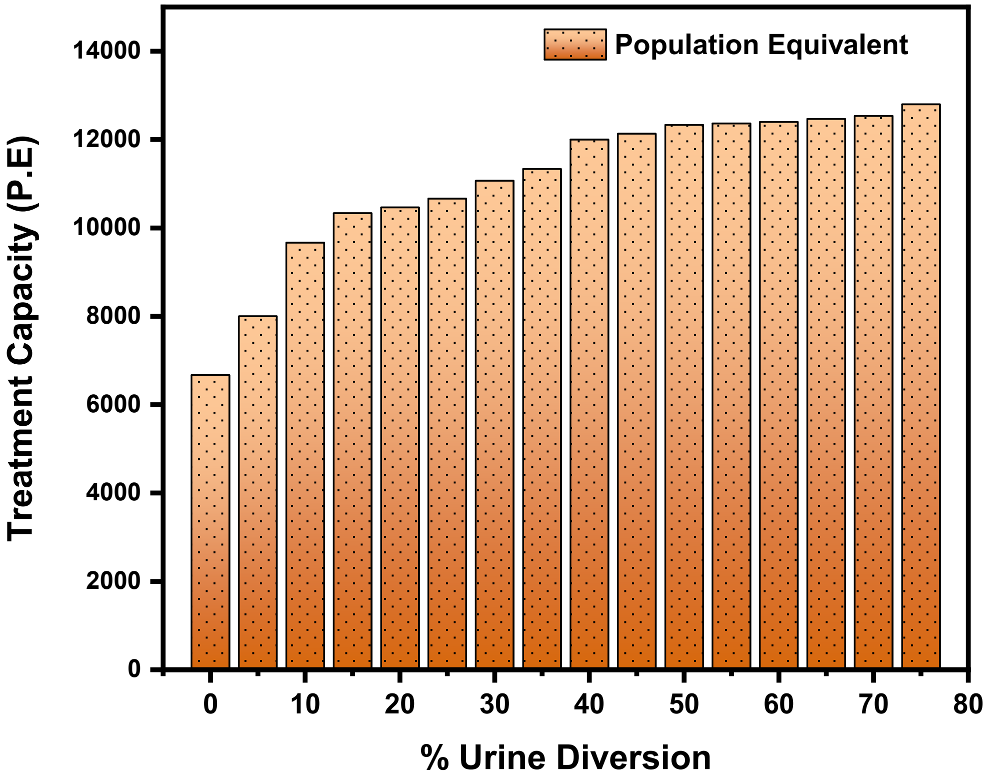


Fig 2. Effect of urine diversion on treatment capacity of Central Park WWTP (~6666 EP). MLSS = 5000 mg/L, effluent total nitrogen and ammonia targets of 7.8 mgN/L and 1mgN/L respectively.

3.2. Process Configuration

In this section, the possibility of modifying the reference or existing configuration of the Central Park WWTP to a simpler process has been evaluated. The effect of urine diversion on effluent nitrogen concentration in process A has been reported in our previous study (Badeti et al., 2021) while processes options B and C have been investigated in this study. Fig 3 shows the effluent nitrogen concentrations when no urine is diverted from the wastewater streams. The effluent nitrogen loads are significantly low (< 7.8 mgN/L) in configuration A since most of the nitrogen is removed via denitrification. But in configuration B and C the concentrations of effluent nitrogen are 58 mgN/L and 78 mgN/L respectively which are much higher than the permissible limit of 7.8 mgN/L without any urine diversion.

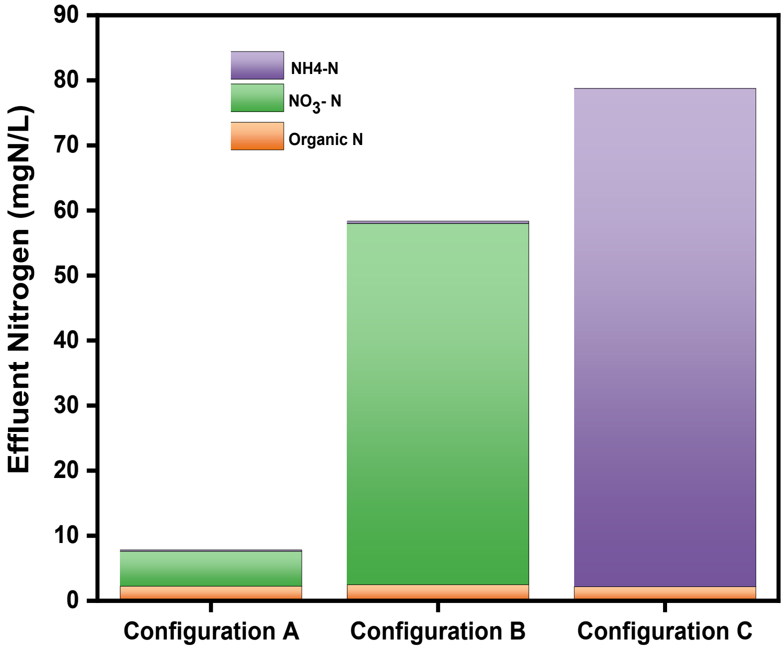


Fig 3. Comparison of the effluent nitrogen concentration in the effluent in the three different processes without any urine diversion. The influent concentration of the raw wastewater assumed are $NH_4 = 72$ mgN/L, $NO_3 < 0.1$ mgN/L, organic-N = 18 mgN/L

a) Process Configuration B

Fig 4 and Fig 5 show the effluent nitrogen concentration and mass balance of nitrogen (diverted, denitrified, removed as sludge wastage, effluent) in Configuration B. As shown in Fig 3 and 4, at 0% urine separation, about 70% of the influent nitrogen is found as nitrate in the effluent and this is due to the absence of an anoxic tank in configuration B unlike in A where most of the nitrogen is denitrified in Configuration A. By increasing urine diversion, the influent nitrogen load is reduced. The influent wastewater COD/N ratio however increases with urine diversion reaching a point where most of the low influent nitrogen is mostly removed as sludge biomass and hence the necessity of an anoxic tank to perform denitrification process is not needed because nitrogen concentration below 7.8 mg/L can be easily achieved. Previously, various studies have observed similar results treating wastewater with a high COD/N ratio (Holakoo et al., 2007; Khan et al., 2011; Rezakazemi et al., 2018). Hence, for more than 75% urine diversion, process B was sufficient to meet the effluent nitrogen concentration targets.

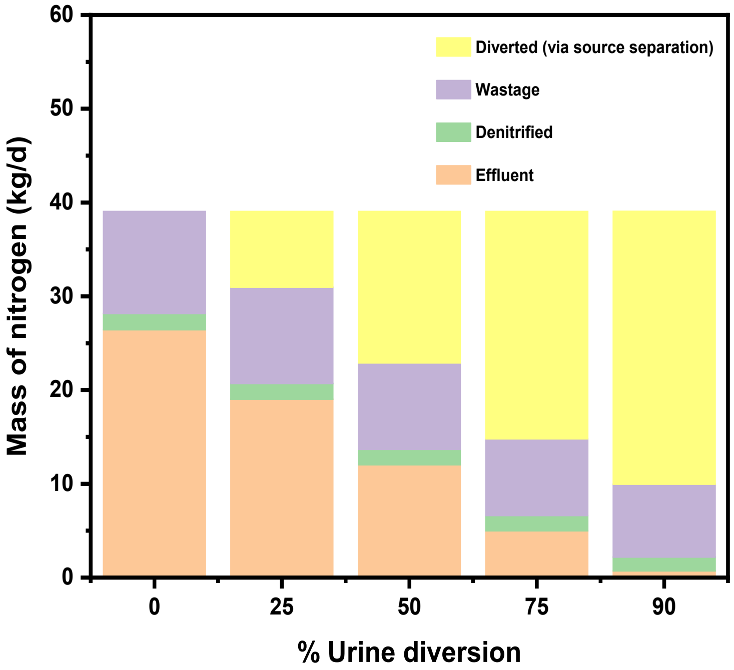


Fig.4 - Fate of nitrogen in Scenario B with urine diversion. WWTP capacity of 1 MLD or 6666 PE. The influent concentration of the raw wastewater assumed are NH_4 = 72 mgN/L, NO_3^- < 0.1 mgN/L, organic-N = 18 mgN/L

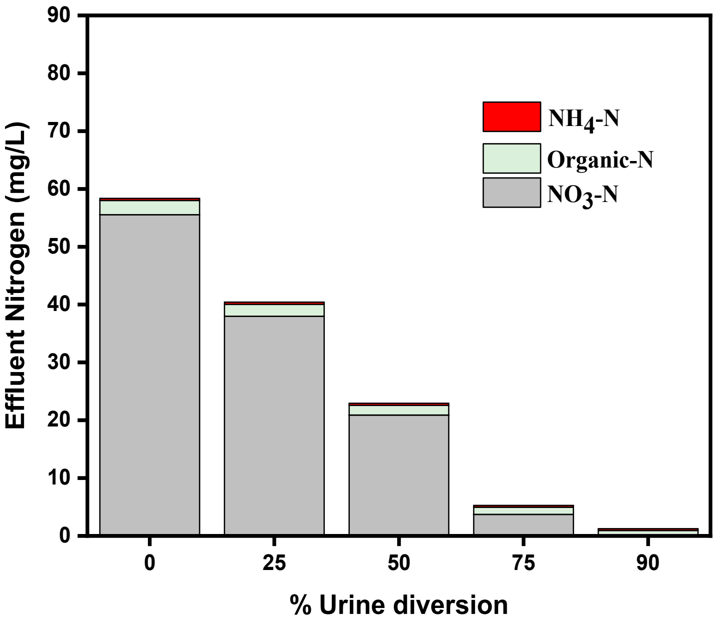


Fig.5 - Effluent nitrogen concentration in Scenario B with urine diversion. The influent concentration of the raw wastewater assumed are NH_4 = 72 mgN/L, NO_3^-< 0.1mgN/L, organic-N = 18 mgN/L

b) Process Configuration C

Fig. 6 and Fig. 7 show the effluent quality and mass balance of nitrogen (recovered, sludge wastage, effluent) with urine diversion in Configuration C. As shown in Fig 6 and 7 at 0% urine separation, about more than 80% of the influent nitrogen was released in the effluent as mostly ammonium. Only a minute fraction of the influent nitrogen is removed through biomass synthesis. It has been reported in the literature that while treating wastewater, the minimum proportion of COD:N:P in the wastewater to be treated should be around 250:5:1 for anaerobic treatment (Ammary, 2004). For anaerobic treatment, the necessary nitrogen and phosphorous concentrations are lower than the case for aerobic treatment because the anaerobic treatment produces less sludge biomass generally compared to the aerobic treatment process (Chan et al., 2009). Hence, only a minute fraction of influent nitrogen is removed as sludge wastage in an anaerobic system. Most of the influent nitrogen is therefore stays in the effluent.

Although with urine diversion, the influent nitrogen loads and hence the effluent nitrogen concentrations can be significantly reduced in configuration C. However, only at 100% urine the total nitrogen is within the acceptable limit of 7.8 mg/L although this is mostly in the form of NH_4-N. The disadvantage of this configuration is that it produces higher effluent ammonium and COD concentrations compared to the reference scenario which can be an issue for the reverse osmosis membrane process for advanced water treatment for water reuse. Higher COD and nutrient concentration make the effluent very high fouling potential for RO operation. A zeolite adsorbent to remove excess ammonia and organics could be added to the reference scenario as an alternative option. Previous studies have reported that adsorption treatment of AnMBR effluent by zeolite can produce similar effluent quality to that of aerobic treatment (Gu et al., 2019; Li et al., 2020). However, these processes require significant use of adsorbents including process complexities in the reuse of adsorbed ammonia. In our case however, the dependence on adsorption is reduced by diverting urine at source and makes the nutrient recovery process simpler. The proposed configuration C is one potential option that can be considered and explored. However, further research is needed to understand the feasibility of these novel integrated processes.

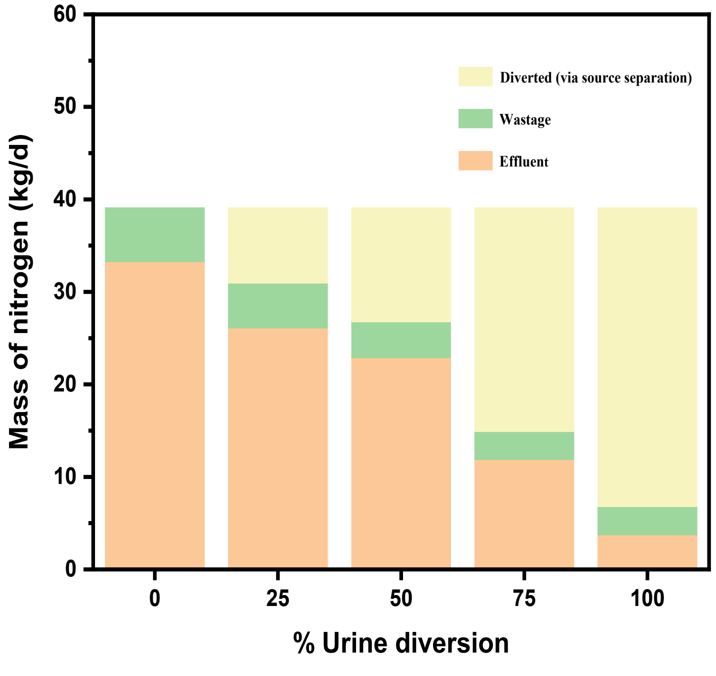


Fig.6 - Fate of nitrogen in Scenario C with urine diversion

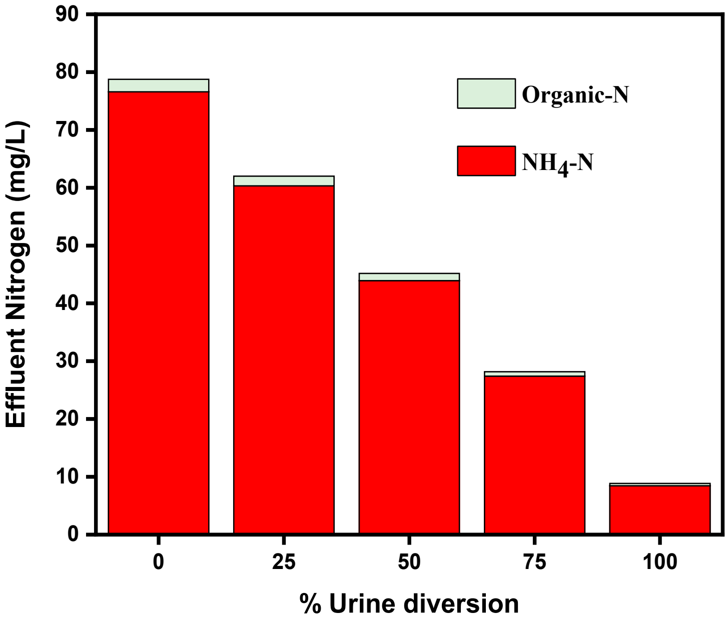


Fig.7 - Effluent nitrogen concentration in Scenario C with urine diversion

3.3. Capital Costs

In the previous section it was observed that the proposed configuration B was able to produce effluent nitrogen (< 7.8 mgN/L) and ammonia (< 1mg/L) concentrations within permissible limits after 75% urine diversion without the need of anoxic tank. In this section, we compared the CAPEX costs of process A and B. Fig 8 shows the capital expenditure per unit treatment on space requirement and civil work for process A and B. Reference scenario (Process A) had a capital cost of 0.78 \$/m^3. Results reveal that 24% of the capital expenditure on space required and civil work could be saved in process B. As expected, the major factors responsible for the CAPEX of the plant are space utilisation cost. In process B, the anoxic tank and recirculation of nitrified mixed liquor are not required as most of the nitrogen is recovered with urine diversion which reduces the associated space and civil work requirements. In this particular case study, we find that most of the capital costs are with space occupancy and the contribution of civil work costs are comparatively less. However, this may not be true in the case of wastewater treatment plants which are located in areas with low land occupancy rates. Hence, these findings may not be applicable to the general wastewater community as space in the heart of Sydney are not representative of most locations.

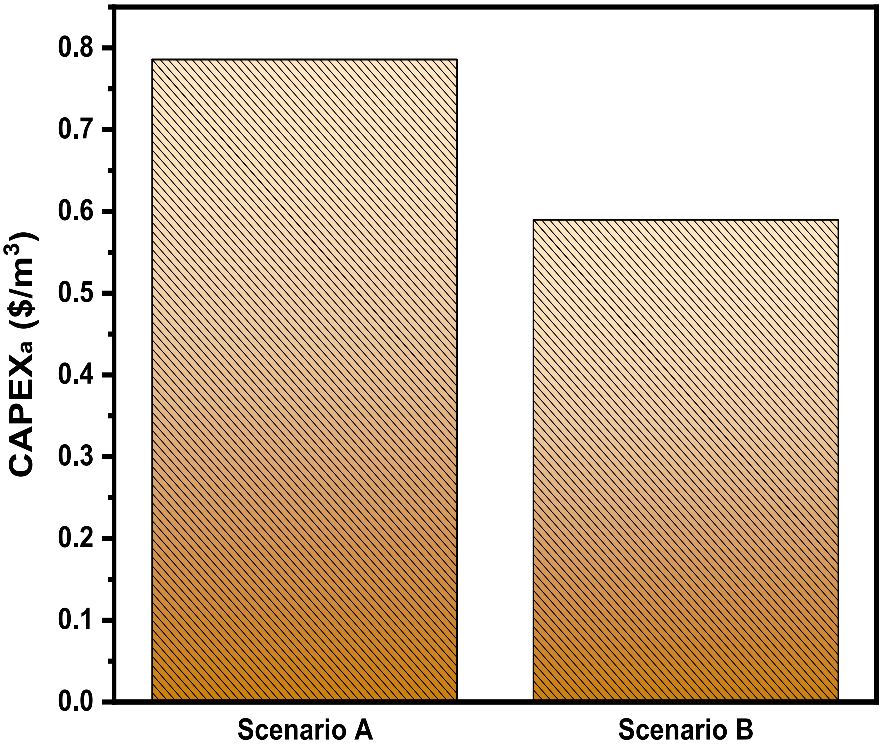


Fig.8 - Capital expenditure of Configuration A and Configuration B (With urine diversion Configuration A can be replaced by configuration B which reduces the capital costs of the treatment process.)

3.4. Sensitivity analysis

Effect of sludge age on treatment capacity

The influence of MLSS concentrations on the capacity of the treatment plant has been investigated in this section under different urine diversion scenario. Earlier in Fig 2, it was shown that the plant capacity does not increase significantly for urine diversion beyond 40%. Fig 9 shows the simulated maximum treatment capacity of the plant for various percentages of urine diversion. These results show that the treatment capacity of the WWTP at higher urine diversion can be significantly enhanced by operating the aerobic bioreactor at a higher MLSS concentrations (simulated for 5, 7.5 and 9 mg/L MLSS concentrations). For urine diversion over 20%, there is a significant increase in the treatment capacity when the bioreactor is operated at 7.5 g/L and 9 g/L increased from 5 g/L as simulated earlier in Fig 2.

Operating at higher MLSS concentration increases the SRT and provides sufficient time for the nitrifiers to oxidise ammonia and produce effluent ammonia < 1 mg/L (Henze et al., 2002; Kos, 1998; Wilsenach & Van Loosdrecht, 2004). For example, at 5 g/L MLSS concentration, the WWTP capacity increases only by 85% when urine diversion is increased from 0% to 50%. However, if the bioreactor is operated at a higher MLSS concentrations of 7.5 and 9.0 g/L, the treatment capacity increases by 168% and 220%, respectively when urine diversion is increased from 0 to 50%. This treatment capacity further increases by 180% and 250% when the urine diversion is further increased from 0% to 75%, which is a very significant increase. The sensitivity analysis therefore indicates that by operating the bioreactor at higher MLSS concentration of 9.0 g/L (instead of 5 g/L) and at 75% urine diversion, the treatment capacity of the WWTP can be increased by about 3.5 times compared to the reference scenario (no urine diversion).

However, MLSS concentration did not significantly impact the treatment capacity for urine diversion below 20% and this is likely because effluent nitrogen was the limiting parameter for treatment capacity below 20%. However, it has been well reported that increasing the MLSS concentrations would decrease the critical permeate flux and lower oxygen transfer rate (Schwarz et al., 2006). It is expected that the membrane surface area and scouring air flow would be increased to obtain critical flux when operated at higher MLSS concentrations. This may increase the capital and operational expenditure of the plant. Further investigations are needed to understand the effect of operating at higher MLSS concentrations on the capital and operational expenditure of the treatment plant.

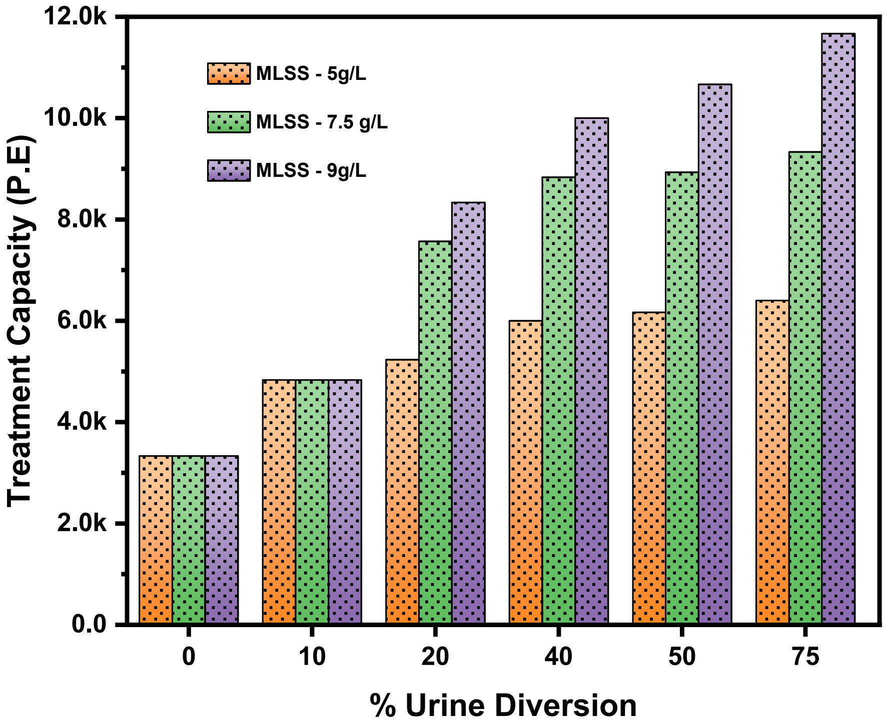


Fig.9 - Effect of operating MLSS concentration on treatment capacity of Central Park WWTP

4. Conclusions

This simulation study demonstrated that urine diversion allows for higher COD loading to the existing WWTP without the need for further process modification but still meets the required effluent nutrient concentrations. Diverting urine up to 75% can help double the treatment capacity of the WWTP, although the rate of enhanced capacity becomes less significant beyond 40% urine diversion. However, the sensitivity analysis indicated that, operating the bioreactor at higher MLSS concentration can significantly help increase treatment capacity even at higher urine diversion rates. At a higher urine diversion, above 75%, it was found that the current complex treatment configuration can be replaced with a simple aerobic membrane bioreactor to produce the same effluent quality significantly reducing plant footprint. Replacing the current process with a simple membrane bioreactor would reduce about 25% of the capital costs mostly due to a reduction in space requirements. The findings of this particular study may not be applicable to the general wastewater community as space in the heart of Sydney are not representative of most locations and hence specific case studies are needed.

CRediT authorship contribution statement

Umakant Badeti: Methodology, manuscript structure, data curation, modelling and analysis, –preparation of original draft manuscript. **Jade Jiang:** Methodology, data curation, manuscript review and editing. **Niren Kumar Pathak**: Data curation, methodology, manuscript review & editing. **Ugyen Dorji**: Review & editing. **Federico Volpin**: Data curation, review & editing. **Stefano Freguia**: Data analysis and visualization, manuscript review & editing. **Ang Wei Lun:** Review & editing. **Sherub Phuntsho**: Methodology, manuscript structure, supervision, project administration, funding and resources, validation of data, interpretation and visualization, manuscript review & editing. **Ho Kyong Shon**: Methodology, manuscript structure, supervision, project administration, funding and resources, validation of data, interpretation and visualization, manuscript review & editing.

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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.

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