Economic and environmental impact analysis of ammoniacal nitrogen removal from landfill leachate using sequencing batch reactor: a case study from Czech Republic

R. Badri Narayan, B. I. Zargham, Audrey Ngambia and Arlieza R. Riyanto

ABSTRACT

Lany landfill, located in the Czech Republic, generates around 10 m^3/d of leachate, heavily polluted with ammoniacal nitrogen, heavy metals and salts, which needs to be treated onsite in order to minimize their effect on the ecosystem and on human health. A sequencing batch reactor (SBR) was designed for ammoniacal nitrogen removal from the leachate and the economic feasibility and environmental impact of the designed SBR was assessed. From the cost-benefit analysis, capital expenditure (CAPEX) of 33,500 €/year and operational expenditure (OPEX) of 13,521 €/year were estimated. A shadow price concept tool was used to calculate the environmental benefit as 21,000 €/year. The net present value of the project was evaluated to be 19,528 € with an internal rate of return of 21.6%. For environmental assessment, triple bottom line (TBL) analysis on the existing practice of discharging the leachate to a nearby wastewater treatment plant and on-site treatment using SBR was performed. The total score for existing practice was calculated to be 55.1% while for on-site treatment it was 59.6%. Based on the results it was concluded that on-site treatment is both economically and environmentally feasible. A mitigation plan was also prepared for the impacts identified in the environmental assessment.

Key words | cost-benefit analysis, reverse osmosis, sequencing batch reactor, shadow price, triple bottom line

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INTRODUCTION

Landfill leachate is defined as an aqueous liquid generated as a consequence of the percolation of precipitation (rain, snow melt) and infiltration of groundwater through wastes, biochemical processes in waste's cells and the inherent water content of wastes themselves (Joshi & Gogate 2019). Leachate is a complex wastewater comprising of a large number of different substances or compounds, mainly organic matter, ammoniacal nitrogen, heavy metals and other dissolved solids. It is estimated that from about a 907 tonne of municipal solid waste, approximately 0.05–0.2 tonnes of leachate can be generated during the whole operational lifetime of the landfill (Kurniawan & Lo 2009; Souza *et al.* 2014). However, the volume of the leachate generated depends on the composition of the waste, age and size of the landfill, the compaction of waste in the landfill, geology of the landfill site and the weather conditions. The components of the leachate are highly polluting substances or compounds with high potential to cause adverse effects on human health and the environment if they not properly managed (Iskander *et al.* 2018). It is therefore essential to properly manage the leachate generated from the landfill and to treat it in order to

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minimize the effect of highly polluting contaminants on the ecosystem and on human health.

The landfill considered in this case study is located at a municipality in the Czech Republic named Lany. Lany landfill receives approximately 8,000 tonne/yr of mixed municipal solid waste from its municipality. The landfill has been operating since 1993 and produces approximately 10 m^3/d of leachate which is highly polluted with organic load, ammoniacal nitrogen, heavy metals, and salts. The landfill currently sends the leachate for treatment to a nearby small municipal wastewater treatment plant (WWTP), which is considered to be an expensive option. However, it is also expected that in the near future, legislation will become more stringent, which may prohibit the treatment of leachate in that particular WWTP. As a result, the landfill installed a reverse osmosis (RO) plant to treat the leachate onsite. However, the existing RO plant seems to have a low ammoniacal nitrogen removal efficiency. Hence, leachate pre-treatment for ammoniacal nitrogen removal before the RO unit is indispensable. This would make sure that the treated leachate will comply with the legislative discharge limit of ammoniacal nitrogen into surface waters. Therefore, the authors have restricted the scope of nutrient removal in this study only with respect to ammoniacal nitrogen, as the other nutrients are considered to be removed efficiently by the RO plant onsite.

Physical–chemical treatment methods are mainly used either as pre-treatment or post-treatment methods to treat landfill leachate. They are employed along with a biological treatment process in order to enhance its efficiency since they have the potential to remove bio-refractory and undesirable compounds such as heavy metals, humic acid, fulvic acid, adsorbable organic halogens (AOXs), polychlorinated biphenyls (PCBs), etc. Different processes such as air stripping, chemical precipitation, and membrane technology have been studied for the removal of ammoniacal nitrogen from leachate (Abbas *et al.* 2009). However, biological treatment was given preference because of the major disadvantages of the physico-chemical processes as mentioned below.

- In air stripping, there is a problem of generation of contaminated gases which requires further treatment with sulphuric and hydrochloric acid, hence making this option unfeasible (De *et al.* 2019).
- Ammoniacal nitrogen can also be removed by precipitating leachate with magnesium ammonium phosphate (MAP). The problem associated with chemical precipitation is that it requires a large amount of chemicals as it takes place at a particular pH range (8.5–9.0) (Chu *et al.* 2018), thus resulting in large sludge production.
- The highest removal efficiency of ammoniacal nitrogen was observed by membrane technology but the drawbacks for this technology are that membranes are susceptible to fouling, it requires treatment of membrane concentrate (Truong *et al.* 2018) and the operation of membrane reactor is very complex, thus requiring a skilled operator.

Sequencing batch reactor (SBR) is a recognized biological treatment strategy with abundant reports in the literature of its successful application to landfill leachate treatment (Gao *et al.* 2015; Torretta *et al.* 2016; Yong *et al.* 2018). It offers various benefits such as suitability to treat low amounts of influent, versatility and robustness to adapt to the pre-visible variations in leachate characteristics over time. If parameters in influent change, process conditions can be modified accordingly, i.e. fill volume, filling rate, aerobic reaction time, anoxic reaction time, sludge age, sludge concentration, carbon source type and amount, among others (Pelaz *et al.* 2018). Considering all the above advantages of SBR, it was hence chosen as the feasible alternative to treat the leachate in this work.

Preliminary studies on the economics and environmental impacts of a project are important to obtain an insight on the feasibility of its application on a larger scale. For economic assessment, cost-benefit analysis (CBA) with environmental impact valuation is a result of the incorporation of environmental criteria in the decision-making process. The EU Water Framework Directive (WFD) provides a very important role to economic analysis and requires that CBA should be carried out with a goal of involving all the benefits, including those whose value is not determined by the market but have a high value because they uniquely contribute to improving societal welfare (Helming & Reinhard 2009). The CBA is a tool which is used to compare the economic feasibility of the implementation of different projects. CBA revolves around a simple concept, that a project should only be commissioned if the

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sum of all the benefits is greater than the sum of aggregate costs (Molinos-Senante *et al.* 2011). As regards the water resources context, it is known that wastewater treatment has significant environmental benefits. The environmental benefits of wastewater treatment refer to the elimination or removal of pollutants such as suspended solids, chemical oxygen demand (COD), nitrogen, phosphorus, etc., from wastewater. However, most of these environmental benefits are not monetarily quantified because they do not have any market value. They are termed as positive externalities in economics. In spite of this, the monetary evaluation of these benefits is quintessential to prove the economic feasibility of wastewater treatment projects using CBA (Molinos-Senante *et al.* 2010).

In this view, the economic assessment of these externalities in the field of water treatment and reuse is gaining particular importance. Godfrey *et al.* (2009) worked on the application of CBA on a greywater reuse facility in India. Likewise, Seguí *et al.* (2009) showed that a travel cost method could be used to evaluate the environmental benefits resulting from wastewater reuse in a wetland restoration project. Chen & Wang (2009) used a net benefit value model for cost-benefit evaluation of reuse projects in a residential area of China. Molinos-Senante *et al.* (2011) studied the CBA of water reuse projects in wastewater treatment plants in Spain.

Project implementation can have several environmental impacts. The concept of sustainability assessment has mainly resulted from the works carried out by technicians of Environmental Impact Assessment (EIA), and Strategic Environmental Assessment (SEA), which in turn has been manipulated by techniques related to policy making (Pope *et al.* 2004). It was suggested by the EIA and SEA practitioners that the environmental assessment could contribute to sustainability by extending its scope to include social and economic considerations along with environmental ones. This refers to a three pillar method or triple bottom line (TBL) concept. The TBL approach considers the three pillars of sustainability, namely, social, economic and environmental aspects, with equal importance in decision making principle (Di Maria & Sisani 2019). The main highlight of the TBL approach is that it emphasises the fact that material gains are not sufficient measures or preservers of well-being of human society and the environment. Although TBL is a sustainable concept, it has certain drawbacks as it promotes potentially competing interests between the three pillars of sustainability, rather than the bondage and interrelationship between them (Plakas *et al.* 2016). Hence, the task of integration becomes cumbersome and endorsing trade-offs results at the expense of the environment. Environmental quality deterioration can occur during different project phases, thus assessment of potential impacts is required. Through environmental impact identification, the feasibility of this project could be assessed.

This work is a case study on a landfill site in Lany municipality of the Czech Republic. The specific objectives of this work are: (i) to design SBR process for removal of ammoniacal nitrogen from the leachate; (ii) to perform economic assessment on the proposed design of SBR using CBA; (iii) to evaluate the economic performance of the project by estimating cash flow, net present value and internal return rate; (iv) to compare and assess the impact of existing practice and on-site treatment on various aspects (environmental, economic, and community); and (v) to prepare a mitigation plan for the impacts observed during the environmental assessment.

MATERIALS AND METHODS

Process design

The process has been designed to treat the landfill leachate having the characteristics shown in Table 1. The proposed process was designed based on the previous works conducted by Neczaj *et al.* (2005) for the treatment of landfill leachate having characteristics similar to those mentioned in this work. Process conditions were set for this design at 10% leachate dilution in the reactor, 4,000 mgMLSS/L, 0.8 mgVSS/mgSS, 10 days sludge age. With these conditions, preliminary calculations were performed to develop the conceptual design for this process. A scheme for SBR treatment process of landfill leachate is presented in Figure 1.

With a leachate production of 10 m^3/d, the required total volume in the reactor was calculated to be 50 m^3 as shown in Table S1 (Supplementary Material). In order to handle two cycles per day, 5 m^3 of leachate at a dilution of

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Table 1 | Average composition of the leachate to be treated

Parameter	Concentration (mg/L)
pH	7.6
BOD	150
COD	2,786
N-NH_4	800
TIC	780
TSS	100
TDS	13,000
SO_4^{2-}	70
NO_3^-	6
Cl^-	2,200
Ba	1.8
Ca	110
Cr	1.5
Cu	0.48
Fe	3
K	1,200
Mg	190
Na	2,050
Pb	0.03
Zn	3.7
Conductivity (microS/cm)	14,000

10% can be treated in each cycle. The number of cycles to be carried out per day was considered to be two in order to avoid the need for a night shift labour. The required dimensions for the SBR tank were estimated to be around 3.5 m in diameter and 6 m in height (Kong *et al.* 2009). For a robust design, the cycle time was estimated at 8 h, divided as: 0.5 h aerobic fill, 4 h aerobic reaction, 2 h anoxic reaction, 0.5 h settle time and 0.5 h draw time (Neczaj *et al.* 2005). Considering the aforementioned conditions, required nitrification and denitrification rates were evaluated for this particular situation. The detailed process calculations are presented in Table S1. Nevertheless, if parameters change, some process conditions can be modified accordingly. In case of concern about nitrifiers' retention in the reactor given the low organic load available for floc forming microorganisms in the aerobic phase, bio-carriers could be added to favour biofilm growth. Given the low organic load present in the leachate, the addition of an external carbon source was required. Methanol was chosen because of its high availability, high COD, low yield and price. Considering the typical COD requirement for denitrification as 4.5 mgCOD/mgN-NO_3 (von Sperling 2007), the TOD of methanol as 1.5 mgO_2/mgCH_3OH, and the estimated amount of N-NO_3 to be removed, the amount of methanol required was estimated using Equation (1). Methanol consumed per day was estimated to be about 28 L/d.

$$\text{Estimated methanol required for denitrification} = \frac{\text{amount of nitrates to be denitrified} * 4.5\ \text{mg COD}/\text{mgN} - \text{nitrate}}{1.5\ \text{mg } O_2/\text{mg methanol}} \quad (1)$$

The optimum pH range for the nitrification–denitrification process to occur is 7.0–8.3 (Raper *et al.* 2018). Nitrification consumes alkalinity which can lead to a drop in the pH level if the buffer capacity of the wastewater is not enough.

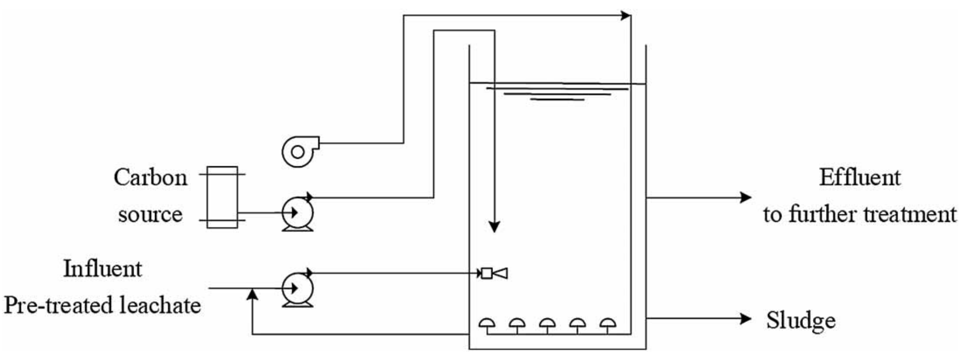

Figure 1 | Schematic of biological leachate treatment using SBR.

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The buffer capacity of this leachate could hence be adjusted as required by adding a suitable form of alkalinity such as $CaCO_3$ (Raper *et al.* 2018). Thus, pH can be brought back to an optimal level for the denitrification process to take place. The tank was filled by using a centrifugal pump. Flow capacity was estimated at 15 m^3/h and pump head was estimated at 7 m.

Aeration will be required to provide oxygen and agitation during the aerobic phase. Considering typical requirements, 1 mgO_2/mgBOD and 4.3 mgO_2/$mgNH_3$ (von Sperling 2007), and typical values for aeration parameters air requirement was estimated to be 100 Nm^3/h at a pressure of around 600 mbar, which is achievable by means of a regenerative blower. Agitation would be required during the anoxic phase. This could be achieved using a mechanical suspended mixer or submersible mixer. To keep costs low in this case, it was achieved by recirculating mixed liquor through a jet nozzle using the same pump used for filling the reactor. A smaller pump was required to add the carbon source for denitrification and some additional electricity was used by the control system and eventual ancillary equipment. Electricity consumption was estimated as 1 kW during half of the cycle to maintain a conservative approach. Sludge will have to be dewatered to 50% solids content using a filter press and then be sent for incineration.

Several reasonable assumptions were made in this conceptual design and the results were compared with typical ranges to check the biological feasibility of the process. Nevertheless, the limitations of this conceptual design are acknowledged and the validation of process parameters and assumptions would be required as an early stage of the project execution. This will require tests that are out of the scope of this work.

Economic assessment

The following assumptions/considerations were made while performing the economic assessment:

- The whole estimation was based on the consideration of an existing RO pilot plant operating in the landfill.
- Environmental benefits were based on ammoniacal nitrogen removal (Molinos-Senante *et al.* 2010).
- Capital costs were estimated from catalogues of wastewater treatment plants.
- No new land was required to construct the SBR tank as the landfill already has enough space.
- Labour cost was not accounted for in the calculation of operation expenditure as there are already operators involved in the existing RO plant and this process will not require additional labour.
- The total period of operation of SBR per year was taken as 350 days, considering 15 days of maintenance.
- The time horizon chosen for this assessment was 10 years to obtain a short conservative evaluation.
- The inflation rate of 3% and the discount rate of 10% was assumed to be constant throughout the period of 10 years (Molinos-Senante *et al.* 2012).

To perform this analysis, the net profit at each year was estimated in a simplified way by estimating capital costs, operation costs and environmental benefits of removing nitrogen from the effluent. Capital costs were split into eight sub items (tank, blower and pumps, diffusers, piping, electricity and control, engineering, construction and sludge dewatering). Operation costs were divided into six different categories (energy, staff, reagents, waste management, maintenance, and others) and estimated using the amounts required according to the conceptual design and market prices obtained from reliable sources. The annualised equivalent cost was calculated to illustrate and quickly compare against the benefits. For the environmental benefit, the shadow price of removing nitrogen from the effluent was taken as 8 €/kg of nitrogen (Molinos-Senante *et al.* 2010). To evaluate the economic performance of the proposed process, the net present value and internal return rate were calculated from Equations (2)–(4):

$$NP = \Sigma B_i - \Sigma C_i \tag{2}$$

where NP is the net profit; B_i is the value of the benefit item i and C_i is the value of the cost item i.

$$NPV = \sum_{t=0}^{T} \frac{NP_t}{(1+r)^t} \tag{3}$$

where NPV is the net present value; NP_t is the net profit at time t; r is the discount rate and t is the time horizon

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of the project.

$$IRR = NPV = \sum_{t=0}^{T} \frac{NP_t}{(1+r)^t} = 0 \quad (4)$$

where *IRR* is the internal return rate.

Cost-benefit estimates for the first year were increased according to expected inflation and the net profit at each year was discounted into the present value by means of a proper discount rate. This is in agreement with the methodology proposed by Molinos-Senante *et al.* (2012). In a detailed assessment for execution, this methodology could be refined and additional details could be included, but for the preliminary feasibility assessment within the scope of this work the current approach was deemed satisfactory.

Environmental assessment

An EIA was performed for two options: (i) hauling of leachate to the nearest municipal WWTP; and (ii) on-site treatment of leachate by the proposed technology (SBR). The method used for impact assessment of the project was TBL evaluation methodology. TBL is a framework of sustainability to measure the performance and success of a business with three criteria: people, planet, profit. It balances the criteria of environmental protection, minimizing community impacts, and minimizing economic impacts (costs) (Di Maria & Sisani 2019). The scoring system was carried out based on how the alternatives under investigation impact various criteria and the weight of each criterion was assigned according to its importance (Alhaddi 2015). In this project, environmental and community impacts were weighted equally at 30% and economic impact is weighted higher at 40%. The scoring, which indicates how effective the requirements have been achieved, as shown in Table S2 (Supplementary Material), was based on a TBL assessment. The scoring was performed on a scale of 1–3 following these guidelines (Plakas *et al.* 2016):

- Score 1, the lowest level, indicates that the option proposed has achieved the least criteria goals, causing major negative impacts and requires significant mitigation.
- Score 2, the mid-level, indicates the option proposed does not achieve all the criteria, causing moderate negative impacts and requiring some mitigation.
- Score 3, the highest level, indicates the option proposed have met all the criteria, giving maximum overall benefit and no mitigation is required.

Table S2 indicates how different phases of the project may affect various aspects such as the environment, community, and economics. Two levels of scoring were used in this assessment, '+' represents phases with minor impacts on the aspects and '++' indicates phases with major impacts (Pope *et al.* 2004).

With regard to these options, several assumptions were considered:

- The community residential area is located in a radius of more than 10 km from the landfill.
- The scope of this evaluation is limited only to the landfill and the activity associated with it.
- The landfill is already in operation, and environmental studies like flora and fauna biodiversity has already been conducted.
- The landfill has plenty of available space, thus no purchase of extra land for construction of a treatment plant is required.
- All the constructions discussed in this work were related to SBR treatment plants only and not for the existing RO plant.

RESULTS AND DISCUSSION

Economic assessment

Using the method presented in the previous section, the estimated capital costs and operational costs were calculated and are presented in Tables 2 and 3 respectively. From Table 2, it can be clearly seen that the SBR tank is the most expensive commodity as it is the significant part of the process and since a great many processes like biological reaction and sedimentation take place in the same tank, it is more expensive than the conventional stirred tank reactors for biological nutrient removal. Capital costs were estimated from catalogues of wastewater treatment plants. Costs estimated from actual purchase orders were increased by 20% to account for inflation and geographical differences, and rounded up to provide a conservative estimation. Complete

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Table 2 | Estimated capital costs

Items	Value (€)
Tank	13,700
Blower and pumps	3,000
Diffusers	300
Piping	1,500
Electricity and control	2,000
Engineering	3,000
Construction	5,000
Sludge dewatering	5,000
Total	33,500

Table 3 | Estimated operational costs

Items	Value (€)
Energy	1,789
Staff	0
Reagents	3,938
Waste management	2,100
Maintenance	2,345
Others	3,350
Total	13,521

calculation report for costs estimation is presented in Table S3 (Supplementary Material).

Energy and reagents consumption, and amount of sludge generated were calculated according to conceptual design as shown in Table S1. The total amount of electricity required per cycle of operation was calculated to be 36.5 kWh. This accounts for the electricity consumed mainly by blowers and pumps as shown in Table S3. The unit electricity price for industries in the Czech Republic was found to be 0.07 €/kWh (Statista 2018). Hence the total cost for energy consumption per year of operation came to be around 1,789 €. The spot price of methanol was estimated to be 0.5 €/kg, from the contract price offered by Methanex Corporation (2019). The cost of disposal for dewatered sludge was found to be 150 €/ton from the current Plzen city waste incinerator rates (ZEVO Plzeň 2019). Maintenance costs were estimated with a heuristic criteria of 7% capital expenditure (CAPEX) according to the authors' experience and is consistent with typical values suggested by practitioners (Wendland 2005). The amount of ammoniacal nitrogen removed per cycle as a result of nitrification and denitrification processes was calculated to be 3.75 kg as shown in Table S1. For the calculation of benefits of nitrogen removal, a shadow price of 8 €/kg of nitrogen removed was used and the total benefits gained per year as a result of nitrogen removal was estimated to be 21,000 € (Molinos-Senante *et al.* 2010).

Inflation was set to 3% since it is the upper limit target for the Czech National Bank (2019) and they have historically succeeded in achieving the lower target. The discount rate was set to 10% yearly, being slightly higher than the Czech National Bank interest rate of 0.75% monthly (Czech National Bank 2018). With these parameters, economic performance of the project was estimated as shown in Table 4 and Figure 2. Total equivalent annualised cost

Table 4 | Cash flow over a period of 10 years

	Year										
Items	0	1	2	3	4	5	6	7	8	9	10
CAPEX (€/year)	−33,500	0	0	0	0	0	0	0	0	0	0
OPEX (€/year)	0	−13,927	−14,344	−14,775	−15,218	−15,675	−16,145	−16,629	−17,128	−17,642	−18,171
Benefits (€/year)	0	21,630	22,279	22,947	23,636	24,345	25,075	25,827	26,602	27,400	28,222
Cash flow (€/year)	−33,500	7,703	7,934	8,173	8,418	8,670	8,930	9,198	9,474	9,758	10,051
Discounted cash flow (€/year)	−33,500	7,003	6,557	6,140	5,749	5,384	5,041	4,720	4,420	4,139	3,875
Cumulative discounted cash flow (€/year)	−33,500	−26,497	−19,940	−13,799	−8,050	−2,666	2,374	7,095	11,514	15,653	19,528

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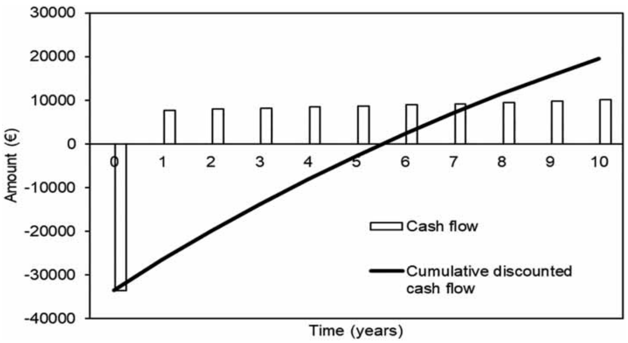

Figure 2 | Economic performance of the design over a period of 10 years.

is 18,973 €/year, which is already a good indicator of good economic performance since it is lower than the estimated benefit. The net present value (NPV) was found to be 19,526 € and the internal return rate (IRR) was estimated to be 21.6%. The payback time was found to be around 5.5 years from Figure 2 and it seems to be a short period of time for a project of this scale.

Environmental assessment

Impacts on the environment and community for both alternatives have been discussed separately in Tables 5 and 6 respectively.

Economic impacts

Option 1: Existing practice: No capital cost is involved and all the cost involved is linked to operation which is the hauling and treatment of leachate at WWTP.

Option 2: On-site treatment: Huge capital investment will be required for the construction of the treatment plant. Regarding the operational cost, it is less i.e. ~4 € as compared to the hauling of leachate to municipal WWTP that costs 8–10 €. Scoring for all the impacts mentioned above are included in Table S2.

Mitigation and monitoring measures

Noise: Noise is one of the main factors that can adversely affect human health if it is more than the permissible limit. It can cause different health related problems such as hearing loss, cardiovascular diseases, reduced productivity or focusing, social handicaps and many more (Münzel *et al.* 2018). It can also affect the calmness and peace of the local community surrounding the landfill facility. Noise at the landfill is mainly produced by the movement of heavy-duty vehicles such as compactors, trucks, etc. So, noise generated within the landfill facility will not only affect the labourers or personnel working there but the surrounding communities will also be effected. In order to mitigate these problems, several measures are proposed (Omar *et al.* 2012):

- an adequate buffer zone between the landfill site and local community should be provided;
- trees such as palm oil can be planted around the facility to absorb the noise;
- keeping the compactors and trucks in good condition to minimize vibrations and noise produced by them;
- providing workers with PPEs (ear plugs) to reduce the exposure to noise;
- the arrangement of cycle schedule for mobilization of materials and equipment;
- instalment of a sound barrier and vibration isolator;
- use of materials that can absorb noise such as foam or fiberglass.

Monitoring of noise level is required to be carried out regularly in the project area using a sound level meter in different representative points and times. The measurements are analysed and compared with the permissible level.

Odour: Another important environmental impact is the emission of odorous compounds from landfill and nuisance created by it. These compounds are produced as a result of decomposition of organic matter, by microorganisms, which is dumped in landfill. According to one study (Mitiani *et al.* 2008), more than 300 trace compounds were detected in the landfill gas. Among these compounds, unpleasant odour is mainly caused by sulphur-containing compounds such as sulphides and mercaptans. Apart from the decomposition of solid waste, odorous emissions are also produced during the landfill leachate treatment such as volatile fatty acids. Similarly, like noise, odour can also create an issue for nearby communities. Thus proper measures need to be taken in order to mitigate this odour problem (Mitiani *et al.* 2008):

- locate the site far from the local communities;

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Table 5 | (a) Environmental impacts of hauling leachate to municipal WWTP and (b) community impacts of hauling leachate to municipal WWTP

	Description
(a) Environmental impacts	
Surface water quality	This option does not affect the surface water quality directly because landfill is not associated with the discharge to surface water but it can have some indirect impacts. For instance, if the leachate contains high concentrations of heavy metals and/or ammoniacal nitrogen, it can affect the performance of the municipal WWTP which can lead to a deterioration of surface water. Thus, a score of 2 was assigned
Greenhouse gases	Greenhouse gases are emitted only during the hauling of leachate which will affect the environment
Chemical use	Since no chemicals are used in this option, it does not have any impact
Treatment plant performance	Since leachate is being mixed with the municipal WWTP, so the plant has to treat wastewater which has high concentrations of heavy metals and ammoniacal nitrogen which can affect its performance
Spills	There can be moderate risks of spilling during the loading, hauling and unloading of leachate. These spills can affect soil, surface water and ground water quality
Flora and fauna	The biodiversity of flora and fauna is not affected since the habitat of the biotic component is not being interfered
Less burden on downstream treatment	Since the leachate is only being transported into the municipal WWTP with no preliminary treatment, it will cause burden to the downstream treatment
(b) Community impacts	
Aesthetics	The hauling process would not have any impacts on the aesthetics since the landfill is isolated
Health and safety	The transportation of the leachate may affect the community nearby and also indirectly impact on the surface water quality that has been mentioned above. Since there is not much labour involved, therefore the magnitude of safety is not the main concern
Job opportunity	No labour is involved in this practice
Odour	During transportation and loading/unloading of leachate some volatile gases can create a fouling smell
Noise	The transportation of leachate using vehicles may create noise
Construction duration	No construction involved
Society perception	Since the leachate is mixed with municipal wastewater, society may have a negative impression, especially on non-governmental organizations (NGOs) in this particular field

- design waste delivery routing and schedule in such a way that receptors have minimum exposure to odorous compounds;
- placing an adequate cover on waste in active cells of landfill every day;
- construction of gas abstraction wells and treatment plant for treating these polluted gases;
- plantation of Golden pothos (*Epipremnum aureum*) (Oyabu *et al.* 2003);
- proper sealing of source (SBR) from where it is originating;
- use of odour neutralizer such as metazene.

Measurement of odour is a very complex process but the chemical or compound responsible for creating that odour can be quantified using different gas detectors or odour monitoring software (Laor *et al.* 2014).

Health and safety: Waste or garbage, if not properly dumped in the landfill site, serves as a major breeding ground for vectors (disease carrying organisms) such as rodents, flies, pest and insects. Moreover, pathogenic bacteria and viruses are also present in this waste. These pathogens cause different diseases to site workers when they are exposed. Diseases include malaria, diarrhoea, cholera, skin and respiratory allergies, Dengue fever, jaundice and many more. Some of these diseases are transferable, so if one person is affected there is a great chance that the staff or workers working with that person can also be affected. Apart from these pathogens, landfill gas is also responsible for causing many

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Table 6 | (a) Environmental impacts of onsite leachate treatment and (b) community impacts of onsite leachate treatment

	Description
(a) Environmental impacts	
Surface water quality	All parameters (pollutants) have been brought under the limits by onsite treatment of leachate. Hence it does not impose any threat to surface water quality
Greenhouse gases	Methane is produced during the decomposition of organic matter which is a potential greenhouse gas
Chemical use	Methanol is used during the biological treatment which is toxic and flammable
Treatment plant performance	Coupling a biological (SBR) with a physical (RO) process enhances the overall removal efficiency of pollutants
Spills	There is no risk of spilling
Flora and fauna	The biodiversity of flora and fauna is slightly affected since the habitat of the biotic component is affected during construction
Less burden on downstream treatment	Since the on-site treatment plant will treat the leachate so there will be less burden on the downstream treatment plant
Gaseous emissions	Ammonia is produced during anaerobic decomposition, which is toxic. Moreover, there will be generation of particulate matter (dust) during the construction phase
(b) Community impacts	
Aesthetics	The construction of the treatment plant would have minor impacts aesthetically
Health and safety	Since there is more labour involved, therefore their safety is important
Job opportunity	Operators will be required for the operation of SBR and RO thus creating new employment opportunities
Odour	Ammonia and hydrogen sulphide are produced during anaerobic decomposition which creates nuisance
Noise	Noise will be produced during the construction and operation phase of onsite treatment plant
Construction duration	It will take approximately six months for the treatment plant to be constructed
Society perception	Since the leachate is mixed with municipal wastewater, society may have a negative impression, especially on NGOs in this particular field. However, society perception may be influenced with the effort of company to perform Corporate Social Responsibility (CSR)
Solid waste	Sludge will be produced which requires proper handling or disposal
Land use	The treatment plant construction will occupy land which may be used for other purposes such as expansion of office buildings, parking lot, etc.

health issues such as birth problems, cancer etc. So, the health and safety of the public and workers can be protected by several mitigation measures (Maheshwari *et al.* 2015):

- the use of personal protection equipment (PPE) such as mask, earmuff, etc.;
- proper training for workers on SBR operation and waste and chemical handling;
- periodic workshop on health and safety;
- by following good hygiene practices;
- ensuring safe and proper handling of waste;
- creating awareness in workers and public regarding the healthcare to improve the life standards.

The health of workers can be monitored by regular medical check-ups and regular supervision or checking of PPE.

Solid waste: toxic sludge is produced as a result of operation of the SBR. The sludge cannot be dumped directly into landfill because it contains active biomass and heavy metals, and thus is toxic in nature. So, in order to dispose of this toxic sludge, it has to be treated. The following methods can be adapted for the treatment of sludge:

- solidification and usage of sludge as a raw material for concrete (Jamshidi *et al.* 2011);
- sludge can be transported to the incineration plant where it can be used as fuel (Stasta *et al.* 2006);

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- utilizing solar energy for on-site drying of sludge beds (Salihoglu *et al.* 2007).

PRACTICAL APPLICATIONS AND FUTURE RESEARCH

Due to the Landfill Directive (99/31/EC), many developed countries in Europe have shifted to other sustainable ways of disposing solid waste instead of landfilling. The number of landfill disposal sites in most of the European countries has been decreasing over the past few years, due to the increase in environmental concern and awareness among governments. Thus, the results obtained from this study would be impertinent with regard to many developed countries in Europe. However, for countries where disposing solid waste in landfill is still prevalent, this research could be fruitful. Many developing countries such as Indonesia, Vietnam, Pakistan, India, Bangladesh, etc., are not equipped with proper landfill leachate treatment facilities and are still looking for cost effective and eco-friendly options. For these countries, this work could be applied as a baseline study for the development of on-site treatment plants. In Cipayung, Indonesia, stabilization ponds such as anaerobic, facultative, and maturation ponds are being used for landfill leachate treatment. The treatment plant's effluent quality still exceeds the standard limits of discharge (Noerfitriyani *et al.* 2018). To achieve the required effluent leachate quality that meets the discharge limits, SBR could be an option to be implemented. Moreover, for developed countries like USA or UK, where financial budget is not a limiting factor, SBR can be coupled with a RO system in order to reclaim the water for reuse inside landfill premises itself.

Based on the above analysis conducted, the following points could be investigated in future for broadening the scope of this study:

- Efficiency evaluation of SBR integrated treatment trains for ammoniacal nitrogen removal and salinity in landfill leachates.
- Economic and environmental assessment of alternative landfill leachate treatment technologies like membrane separation, coagulation, precipitation, etc.
- Study on the effects of other nutrients present in the leachate on ammoniacal nitrogen removal.
- Economic feasibility of landfill leachate management: impact of landfill specific site conditions, local regulations and leachate quality.
- This study is relevant for cold climatic countries. However, a similar study can be carried out for hot climatic countries in order to assess the effect of temperature on the performance of SBR.
- Various sludge management and treatment methods can also be compared and studied in the future.

CONCLUSIONS

The SBR was designed to remove ammoniacal nitrogen from Lany landfill leachate and has now been found to be both economically and environmentally feasible. The economic performance was assessed using cost-benefit analysis, estimating the environmental benefit through a shadow price concept tool, and satisfactory results were obtained. Shadow price methodology provided the implication of monetary value to the unaccountable positive externalities, thereby emphasizing significant importance to environmental benefits in addition to monetary benefits, which is very important in wastewater treatment studies due to growing concern over pollution and more stringent standards in the near future. Profit is estimated to be positive since total annualised equivalent cost is lower than benefit. The net present value is 19,526 € and the internal return rate is 21.6%. The TBL method was used for environmental impact analysis due to its sustainable approach of taking all the three main pillars, namely society, economics and environment, into account. Assessment of environmental, economic, and community impact on the existing practice (total score 55.1%) and on-site treatment (total score 59.6%) was compared. On-site treatment provides a lower impact in various aspects and it can be concluded that it is feasible to be implemented economically and environmentally. A mitigation plan was also prepared for the impacts identified, especially for noise, odour, health and safety aspects.

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SUPPLEMENTARY MATERIAL

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