# Leachate characterization and pollution index as a tool for landfill management: The case of Nsumia Waste Facility in Accra, Ghana

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**Abstract**

Landfills are most countries' primary structures by which solid wastes are disposed of. However, most landfills are not properly engineered and therefore tend to pose a threat to health and the environment, especially through the leachate they produce. The leachates are difficult to treat and, in most cases, are either not adequately treated or not treated at all before release into the environment. This study was conducted to identify the dominant pollutants, assess leachate pollution potential, and identify a suitable treatment approach to leachate from an active municipal solid waste landfill site in Accra, Ghana. Physico-chemical and biological results from leachate analyses indicated the landfill site was in its methanogenic phase. The overall leachate pollution index (LPI) of 12.55, LPI organic ($LPI_{org}$ = 19.08), and LPI inorganic ($LPI_{in}$ = 16.00) were much higher than the standard values for treated leachates before disposal into the environment. Individual pollution ratings show that TDS, Hg, COD, and BOD were the major pollutants influencing the leachate pollution indices. Based on the fact that the organics and the inorganics are the major influencers of leachate toxicity, the tandem operation of co-treatment with wastewater and membrane bioreactor treatment of leachate is recommended.

**Keywords:** Leachate Pollution index; Contamination; Ecological risk, Nsumia; Ghana

## Introduction

Urbanisation comes with technological advancement, increased consumption, as well as increased generation of waste (Saptoka et al, 2023). This is especially true for developing countries where urbanising rates are high (Zurbrugg, 2003) yet there are no corresponding adequate and appropriate management systems for waste. Landfills are the commonest structures for solid waste management in the developing countries, and indeed for waste generated worldwide (Gao et al, 2015).

A common attribute of landfills is the generation of toxic, obnoxious and highly contaminating effusion commonly referred to as leachate. The leachate, if not treated, can pollute ground and surface waters, as well as the soil (Zamri et al, 2017), because they often contain suspended solids and ammoniacal nitrogen which are potentially toxic, both to aquatic and soil organisms (Salem et al., 2008). By nature, leachates are generally known to be composed of organics, inorganics and heavy metal pollutants, and are very difficult to treat. Leachates vary widely in composition depending on the age of the dumpsite and the type of waste that it contains (Abdel-Shafy et al., 2024, Frascari et al., 2004) as well as precipitation, site hydrology, interaction of leachate with the environment, among others (Foul et al., 2009).

Leachates composition determines their toxicity, and knowledge of leachate composition helps in diagnosing the type of treatment that it should receive. It is therefore important to characterise and quantify the type of pollutants in landfill leachate for successful treatment and management. The Leachate Pollution Index (LPI) is currently used to quantify the potential of leachate to contaminate or cause pollution (Umar et al., 2010). Whereas the LPI determines the pollution ability of leachate, it does not in any way indicate the chemical composition of the leachate. Thus determination of chemical composition to assess which pollutant(s) is/are predominant is key to successful leachate management. In line with this, Kumar and

Alappat (2005) proposed sub-leachate indices (sub-LPI) to determine dominant pollutants and their characteristics in leachates. The sub-leachate pollution indices are categorised as organics ($sub\text{-}LPI_{org}$), inorganic ($sub\text{-}LPI_{org}$), and heavy metals ($sub\text{-}PLI_{hm}$).

Over a period of 15 years, urban areas in Ghana witnessed a rapid annual population growth rate, with that of Accra being 4% (Badoe, 2014). The rapid growth and urbanisation, coupled with higher standard of living has inevitably led to increased generation of waste. Ghana generates about 13,000 tonnes of waste daily with only Accra contributing 2,800 tonnes (Makarichi et al., 2018, Lissah et al., 2021). Disposal and management of these wastes remain a major challenge and it has become more and more difficult due to the increasing rate of human population, industrial and technological revolutions. Very few landfills have been constructed in the metropolis; open dumpsites however, are a common sight. As dumpsites spring up over the urban landscape, there is the concern of groundwater contamination by leachates. There are therefore attempts by city and metropolitan authorities to contain the leachates, as the first step towards their management and then subsequent safe release into the environment.

Due to the inadequacy of properly constructed landfills, old quarries are commonly converted into landfill sites of convenience. The Nsumia waste disposal site is one such old quarry in Accra that has been converted to a solid waste dump facility. It is an important waste facility with a size of about 22,000 metres square and a depth of 25 metres. It receives an estimated amount of 800 – 1000 tons of waste from an average of 80 – 100 trucks daily. Being located in the southern part of the Eastern Region of Ghana, and bordering the northern part of the Greater Accra Region, it conveniently serves the two metropolises. The fact that it was an old quarry that was converted to manage waste implies it was not properly engineered, in the first place, to serve the purpose of a proper landfill. For instance, it lacks leachate treatment and stabilisation ponds, monitoring wells, and provision for methane gas collection. Leachate often spills across the surrounding land and this is of serious concern to residents within the vicinity who also cultivate the land for vegetables and other crops. Although the Nsumia waste facility was officially commissioned in 2017, there is already serious agitation by the community for its decommissioning because it is claimed to have been in use long (since 2014) before its commissioned date and has therefore outlived its useful years, judging from the operational deficiencies and obnoxious smell that persistently emanate from the facility and the leachate.

This study therefore seeks to: 1) determine the pollution index of leachate from the Nsumia Waste Facility and propose an appropriate treatment of the leachate. 2) characterise the leachate from the Nsumia solid waste facility and determine the age/phase of the landfill, as an attempt to justify its continuous use or decommissioning.

## Materials and Methods

*Leachate and soil samples collection*

Sampling was done once a month for six months. On each visit, four composite leachate samples were collected from two (2) major leachate outlets. One composite sample was collected into a 500 ml plastic bottles and acidified with 2 ml concentrated nitric acid for heavy metal determination. Another 500 ml non-acidified leachate sample was taken for ex-situ physico-chemical analyses. A third sample of 250 ml was collected into a BOD bottle for BOD analysis and a fourth sample of 250 ml was taken into a wide mouth, pre-sterilised glass bottle for total coliform enumeration. Parameters such as: temperature, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO) and pH of leachate samples were measured in situ with a HORIBA U-50 series multi-meter checker. After each reading, the meter was rinsed with distilled water. The samples were transported on ice to the laboratory for further analyses.

*Laboratory analyses*
Samples that were not analysed immediately were stored in a refrigerator. The physico-chemical properties of the leachate were analysed according to standard methods (APHA, 2005). Parameters like nitrate-nitrogen ($NO_3$-N), ammonia-nitrogen ($NH_3$-N), total phosphorus and sulphate were analysed by spectrophotometry, using HACH Model DR 2010 spectrophotometer. Chemical oxygen demand (COD) was also determined spectrophotometrically after digestion and the 5-day BOD test was used to analyse biochemical oxygen demand ($BOD_5$). Chloride was determined by the silver nitrate ($AgNO_3$) titration method.
Heavy metals in leachate samples were analysed by PERKIN ELMER atomic absorption spectrophotometer (AAS) model Pinaacle 900T after digestion. Leachate samples were digested with 1ml of Hydrochloric acid (HCl) and 2 ml of Nitric acid ($NH0_3$) mixture. The heavy metals analysed were: Chromium (Cr), Lead (Pb), Cadmium (Cd), Iron (Fe), Copper (Cu), Nickel (Ni), Manganese (Mn), Mercury (Hg) and Zinc (Zn). For total coliform enumeration in leachate, samples were incubated on Violet Red Bile Agar at 37°C for 24 hours.

*LPI calculation*
The leachate pollution index (LPI) was calculated according to the procedure given by Kumar and Alappat (2003a). The LPI is a single number ranging from 5 to 100, which expresses the overall contamination potential of a landfill, based on severe pollution of 18 parameters. It is an increasing scale index, where a higher value indicates a poor environmental condition (Kumar and Alappat, 2003b). The higher the index, the more polluted and therefore greater the potential of the leachate to cause contamination in the environment. The LPI is calculated using equation (1)

$$\boldsymbol{LPI} = \sum_{i=1}^{n} wipi \qquad (1)$$

Where **LPI** is the weighted additive leachate pollution index; $\boldsymbol{w_i}$ is the weight for the $i^{th}$ pollutant variable; $\boldsymbol{p_i}$ is the sub-index score of the *i*th leachate pollutant variable; ***n*** is number of leachate pollutants variables (18) used in calculating LPI (18) and $\sum \mathbf{wi} = 1$.
The 'P' values or sub-index values for all the parameters analysed were computed from the sub-index curves (Appendices 1 – 3, according to Kumar and Alappat, 2005) based on the concentration of the leachate pollutants obtained in this research. The 'P' values were obtained on a vertical axis by locating the concentration of the leachate pollutant on the horizontal axis of the sub index value where it intersected the curve. The 'P' values obtained for the parameters analysed were multiplied with the respective weights assigned to each parameter, and the cumulative value gives the LPI.
Out of the 18 parameters used for the calculation of LPI, phenolic compounds, cyanide, arsenic (As) and total kjeldah-nitrogen (TKN) were not analysed in the present study. Therefore, the modified equation (2) as described in Kumar and Alappat (2005) was used to calculate the LPI as follows:

$$LPI = \frac{\sum_{i=1}^{n} wipi}{\sum_{i=1}^{n} wi} \qquad (2)$$

Where:
LPI = Leachate pollution index,
*wi* = Weight of the ith pollutant variable,
*pi* = Sub index score of the ith leachate pollutant variable,
n = Number of leachate pollutant variables used in calculating LPI = 14

*Calculation of sub-indices of leachate pollution index*
The 18 leachate pollutant variables selected for the LPI can also be grouped into three components so as to formulate three sub-LPIs in terms of the leachate's organic ($LPI_{or}$), inorganic ($LPI_{in}$) and heavy metal ($LPI_{hm}$) compositions (Kumar and Alappat, 2005). The three sub-LPI scores are calculated separately as individual indices. The weight factors for pollutants in each sub-group is calculated on a scale of 1 and are as presented in appendix 4.

Since data for all pollution variables were not available in this study, the sub- LPI scores were calculated using equation (2). The aggregation of the three sub-LPIs gives the overall LPI (Kumar and Alappat, 2005) according to the Equation (3):

$$LPI = 0.232LPI_{or,} + 0.257\ LPI_{in} + 0.511\ LPI_{hm} \qquad (3)$$

Where LPI is the overall leachate pollution index; $LPI_{or}$ is the subleachate pollution index of organic components; $LPI_{in}$ is subleachate pollution index of inorganic components and $LPI_{hm}$ is subleachate pollution index of heavy metal components.

## Results and Discussion

*LPI and sub-LPI*

The overall LPI of the landfill leachate understudy was 17.37 (Table 1). This value exceeds 7.378, which is the disposable LPI limit that treated leachate needs to attain before disposal into any surface water body (Kumar and Alaappat, 2003a). The high LPI value signifies that the surrounding lands of the dumping ground and any ground water within the vicinity could be contaminated. The leachate therefore needs to be properly treated before discharging into the environment. Umar et al., (2010) determined the LPIs of four landfill leachates in Malaysia and recorded values in a range of 16.44 – 23.45. Kumar and Allapat (2005) also had a value of 19.66 for a North Yorkshire landfill in the United Kingdom. In comparison, the LPI of the landfill in this study is slightly lower.

The three sub-LPIs calculated in order to determine which category of pollutants contributes more significantly to the overall pollution potential of the leachate had the descending order of magnitude: $LPI_{org}$ (39.88) > $LPI_{in}$ (16.00) > $LPI_{hm}$ (7.85), The same order was recorded by Kumar and Allapat (2005), however, the $LPI_{hm}$ in the current study was higher than that recorded by them (5.53). The three sub-LPI were much higher than the sub-indices standard values for treated leachate ($LPI_{org}$, 7.03; $LPI_{in}$, 6.57 and $LPI_{hm}$, 7.89) (De et al., 2016) before disposal into inland surface waters. It is obvious from the current study that pollution parameters such as TDS, Hg, Coliforms and BOD are the main influencing

**TABLE 1**

Leachate Pollution Sub-indices and Overall Leachate Pollution Index of leachate

| Index | Parameter | Concentration (mg/L) | Sub-index value (Pi) | Weight factor (Wi) | WiPi |
|---|---|---|---|---|---|
| Organic | BOD | 424 | 20 | 0.263 | 5.26 |
| | COD | 850 | 30 | 0.267 | 8.01 |
| | Total Coliform | 1.5×103 | 75 | 0.224 | 16.80 |
| | *Summation* | | | 0.754 | 30.07 |
| | ***$LPI_{org}$*** | | | | **39.88** |
| Inorganic | pH | 7.99 | 5 | 0.214 | 1.07 |
| | TDS | 18383.00 | 45 | 0.195 | 8.775 |
| | NH3-N | 2W2.26 | 5 | 0.198 | 0.99 |
| | Cl- | 1381.00 | 10 | 0.187 | 1.87 |
| | *Summation* | | | 0.794 | 12.705 |
| | ***$LPI_{in}$*** | | | | **16.001** |
| Heavy metals | Zn | 0.025 | 5 | 0.11 | 0.55 |
| | Cu | 0.11 | 5 | 0.098 | 0.49 |
| | Cr | 0.62 | 5 | 0.125 | 0.625 |
| | Pb | 1.07 | 8 | 0.123 | 0.984 |
| | Fe | 11.83 | 5 | 0.088 | 0.44 |
| | Ni | 0.93 | 5 | 0.102 | 0.51 |
| | Hg | 0.14 | 20 | 0.121 | 2.42 |
| | *Summation* | | | 0.767 | 6.019 |
| | ***$LPI_{hm}$*** | | | | **7.847** |
| | **Overall LPI = 0.232 $LPI_{org}$ + 0.257 $LPI_{in}$ + 0.511$LPI_{hm}$** | | | | **17.374** |

$LPI_{org}$ = Leachate Pollution Sub-index of organics;
$LPI_{in}$ = Leachate Pollution Sub-index of inorganics;
$LPI_{hm}$ = Leachate Pollution Sub-index of heavy metals

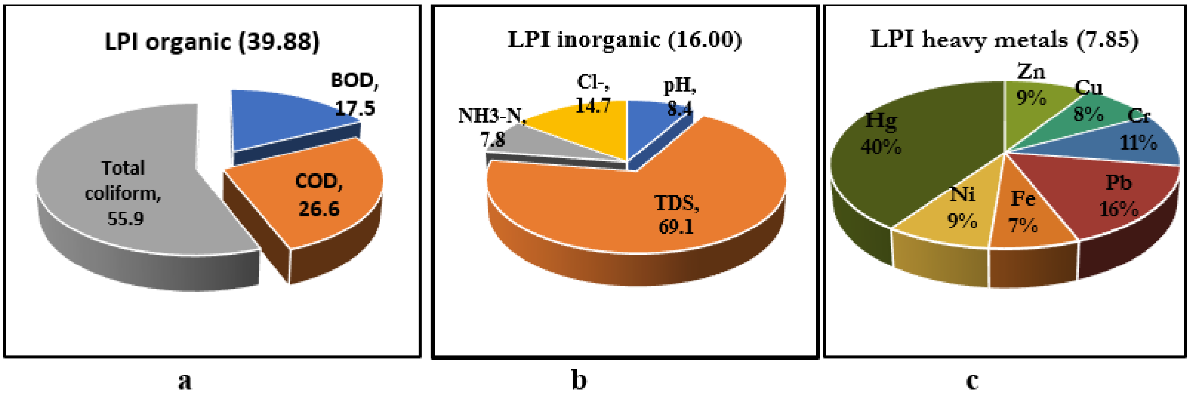


**Figure 1** GPercentage distribution of the components of (a) LPI organic, (b) LPI inorganic and (c) LPI heavy metals for the Nsumia waste dump leachate

factors (Table 1). Total coliform was the major pollutant in $LPI_{or}$, contributing about 56% in the dumping ground (Fig. 1). TDS was the major pollutant for the $LPI_{in}$ contributing, about 69% whilst among the heavy metals, Hg was the dominant pollutant in $LPI_{hm}$ and contributed about 40% in the dumping ground (Fig. 1).

*Leachate treatment approach*

Considering that the major contributors to the overall LPI are the organics and to a lesser extent, the inorganics (mainly TDS), any leachate treatment approach must necessarily factor how to handle these two. Whereas biological treatment approach may be suitable for handling the organics, the same does not apply for inorganics such as $NH_4^+$-N and TDS. A high TDS in particular (like in the current study) can be problematic since it reflects the extent of mineralisation and can change the physical and chemical characteristics of receiving waters, as well as increasing toxicity by changing the ionic composition of water (Al-Yaqout and Hamoda, 2003). As a matter of fact, the presence of high TDS in leachates often poses difficulties in the biological treatment. According to Mojiri et al., (2021), the most reported landfill leachate treatment approaches are biological, physico-chemical, co-treatment with wastewater or a combination of some of these approaches (Figure 2). In the case of Nsumia Waste Facility, there will be a need for an approach that can handle both the organics and the inorganics and such approach should be effective yet cheap, to be affordable to developing countries like Ghana. Since wastewater processes are very efficient in treating organic matter contents, most leachates from landfills in the category of young to early maturation can conveniently and effectively be co-treated with wastewater. This approach, which is currently gaining more acceptance, is quite appropriate for most developing countries, since there will be no need to invest in a separate set-up for leachate treatment. However, if the leachate contains significant chemical contaminants, then two or more approaches in tandem may have to be considered. One approach that has been recommended from many studies is the membrane bioreactor (MBR) treatment. It is considered as a good integration to conventional biological treatment of sludge and leachate. For instance, studies have reported high removal efficiencies (>95%) for various membrane treatments including ultra-filtration, microfiltration, nano-filtration and reverse osmosis for both organics and inorganics such as NH4-N, Cl- and total nitrogen which contribute to high TDS (Mahmoudkhani et al 2011; Ahmed and Lan

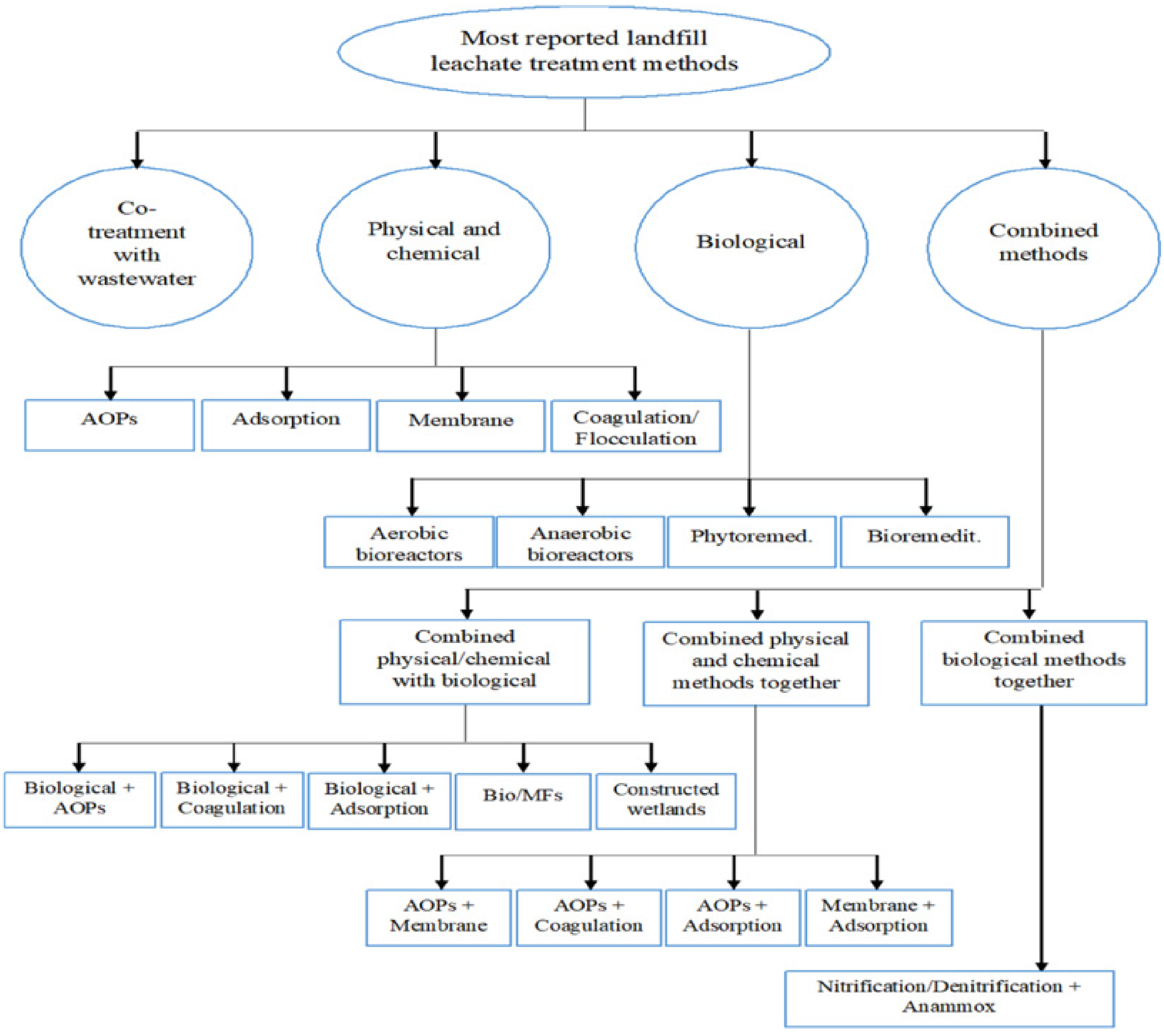


**Figure 2** Common landfill leachate treatment methods Source: Mojiri et al., (2021)

2012; Abdel-Fatah, 2018; Yazdi, Vosoogh and Bazargan, 2018; Teng et al, 2021). It is therefore possible, in the case of this study to couple biological process with membrane filtration in a set-up to reduce the TDS component of the leachate.

*Leachate characterisation and age of landfill*

Landfills have life spans, at the expiration of which they have to be decommissioned. However, most landfills tend to be in operation even when they are over-aged, due to uncertainty of its operational life, coupled with lack of availability of enough disposal facilities. This is especially true of developing and under-developed countries. However, assessment of leachate composition (characterization) and characteristics can indicate or give a fair prediction of the stage, transition phase, or age of any landfill. Characterization establishes the characteristics of the leachate (Teng et al., 2021), and these characteristics are defined by basic parameters such as COD, BOD, BOD/COD ratio, pH, suspended solids, $NH_4^+$-N, total Kjeldahl nitrogen, chloride, and heavy metals. Since the age of landfills affect the composition and levels of these parameters in leachates (Teng et al., 2021), their proper characterization can help in estimating the age or phase of landfills and hence facilitating their management and proper planning.

Most organic or inorganic parameters of leachate decrease in concentrations with increasing leachate age and stability (Tatsi and Zouboulis, 2002) and they also indicate whether the waste facility is active. The pH of leachates is generally found to be between 4.5 and 9 (Umar et al., 2010). That of young leachate is often less than 6.5 – and indicative of an acidogenic phase - while the value for old leachate is higher than 7.5 (Christensen et al., 2001; Umar et al., 2010). The pH of leachate in this study (7.99) (Table 1) therefore indicates the leachate to be at the methanogenic and stabilisation phase as a result of ageing. De, et al., (2016), Agbozu et al., (2015), and Tatsi and Zouboulis, (2002) also reported similar range of pH from old landfills. According to Farquhar (1989), BOD of mature and stabilising landfills (5 – 10 years) ranges between 1000 – 4000 mg/L while that for old landfills (10 – 20 years) ranges from 50 mg/L to 1000 mg/L. Similarly, Pohland and Harper, (1985) observed that BOD value of 100 - 10,000 mg/L indicates leachate is in transition phase where there is influence of dilution and aerobic solubilization of organics in waste. Thus, the BOD value of 432.98 mg/L as observed in the current study is an indication of waste decomposition in the methanogenic phase and it is typical of transitioning landfills. This fact is corroborated by De et al., (2016) and Kjeldsen et al., (2002) who observed that Leachates in the methanogenic phase are characterized by lower concentrations of heavy metals, as it is in this case. The lower heavy metal concentration, according to Kjeldsen et al., (2002) is as a result of sorption and precipitation reactions with the co-existing sulphides, carbonates and hydroxides. Osei et al., (2011) recorded a similar pH value of 7.7-8.5 at the Oblogo Landfill at a different location of Accra, Ghana. The high alkalinity of the leachate as a result of the high pH values is also indicative of high organic strength of leachate as observed by Osei et al., (2011) and this may be as a result of volatile fatty acids removal by methane producing bacteria and bicarbonate dissolution (Pohland and Harper, 1985; Tatsi and Zouboulis, 2002). The COD value for the leachate (850 mg/L) also suggests leachate at the transition phase. According to (Farquhar, 1989), TDS of young (0 – 5 years) and mature landfills (>10 years) leachates have ranges of 10,000 – 25,000 mg/L and 5,000 – 10,000 mg/L respectively. The TDS value of 18,383 mg/L thus places the Nsumia Facility in the young to mature age bracket.

Table 2 provides insight on possible age of the Nsumia facility vis-à-vis general age characteristics of landfills. Kurniawan et al., (2006) and Rivas et al., (2004) stipulated that the ratio of the concentrations of $BOD_5$ and COD also indicates age of landfill leachates. A $BOD_5$/COD value between 0.5 – 1.0 points to young leachate, while a ratio of less than 0.1 implies old leachate. From the current study, leachate characteristics like pH, BOD, COD, heavy metal and NH3-N place the landfill in the mature-to-old category, while TDS indicates young landfill. TDS comprises mainly inorganic and dissolved organics (Agbozu et al., 2015). Once the facility is in use, organic and inorganic materials will continue to be dumped. The breakdown of the

**TABLE 2**

Leachate characteristics and age of landfills

| Parameter | Young | Medium/ Transition | Old | Nsumia | |
|---|---|---|---|---|---|
| | | | | Parameter Value | Landfill age categorization |
| pH | < 6.5 | 6.3 – 7.1 | > 7.5 | 7.9 | Old |
| BOD | 7,500 – 17,000 | 1000 – 4000<br>100 – 10,000 | 50 – 1000 mg/L | 432.98mg/L | old |
| COD | 480 – 18,000 | 580 – 10,000 | 31 - 900 | 850 | Transition - old |
| BOD/COD | 0.5 – 1.0 | 0.1 – 0.5 | < 0.1 | 0.499 | Transition |
| NH3-N (mg/L) | 120 - 125 | 6 – 430 | 6 - 430 | 22.26 | Transition - old |
| Heavy metals | High | medium to low | Low | Low | Old |
| TDSmg/l | 10,000-25,000 | 5,000-10,000 | - | 18,383 | Young |

organic and the inorganics contribute to TDS and so even old landfills, that are still heavily in use, will continue to register appreciable levels of TDS. This explains why the TDS level of the Nsumia leachate is high. The Nsumia Waste Facility can therefore be said to be in transition phase. Even though the facility was officially commissioned for use in 2017, the managers confirmed that it was already in use way back in 2014. It is therefore not as young as the commission date will suggest.

## Conclusion

This study establishes that leachate from the Nsumia landfill, with an overall LPI of 12.55 is above the standard value of 7.378 for safe disposal into inland surface waters. As per the individual pollutant ratings, TDS, COD and BOD were the highest. Evaluation of the sub-LPIs indicates that a combination of biological and membrane bioreactor (MBR) approach is a suitable option in treating the leachate since it is more likely to treat the dominant organics as well as the significant presence of the inorganics. The characterized values of the leachate parameters, such as its slightly alkaline nature, low levels of heavy metals, $NH_3$-N, BOD and COD signify that the landfill is transitioning into a matured/ old phase. Thus the concern of citizens for its immediate closure can be said to be a bit premature. Notwithstanding, the authorities must start planning for its decommissioning in the nearest future since the landfill is already transitioning into the mature phase. In order to overcome some of the inconveniences that come along with the operation of the facility, it is recommended that: 1. the fumigation that is periodically done in the area must be more frequent, at the waste facility, the environs as well as homes in order to reduce the numbers of insect pests, rodents and other vermin, 2. compaction of the waste in the facility must also be carried out more frequently than it is now to prevent easy dislodgement of waste materials during windy and rainy conditions. 3. if leachate treatment cannot be done on-site, proper stabilization ponds can be constructed to hold the leachate for some time to allow for natural biological treatment by bacteria breakdown of the organic materials. This will also reduce the level of the smell, as well as the discharge of the leachate into the community.

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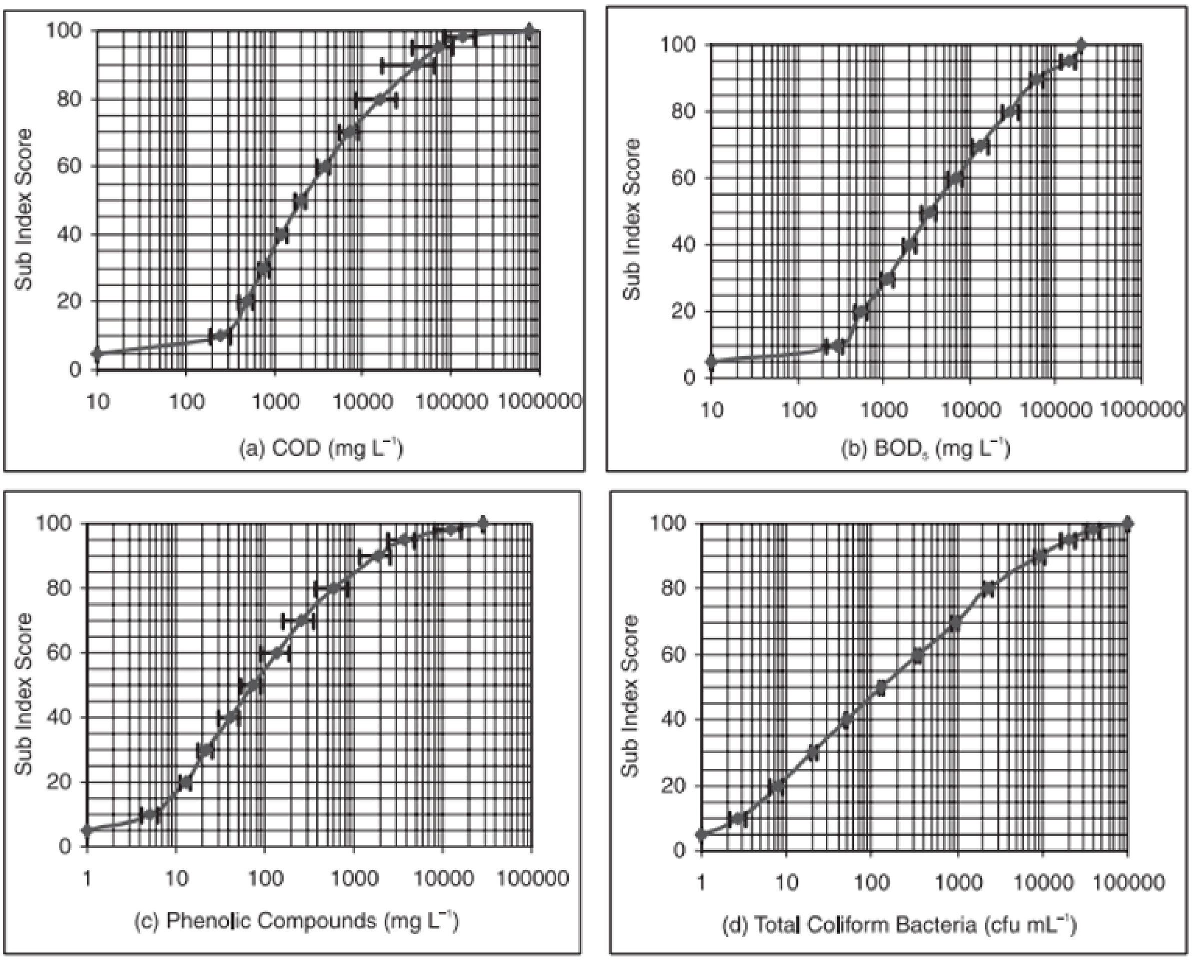
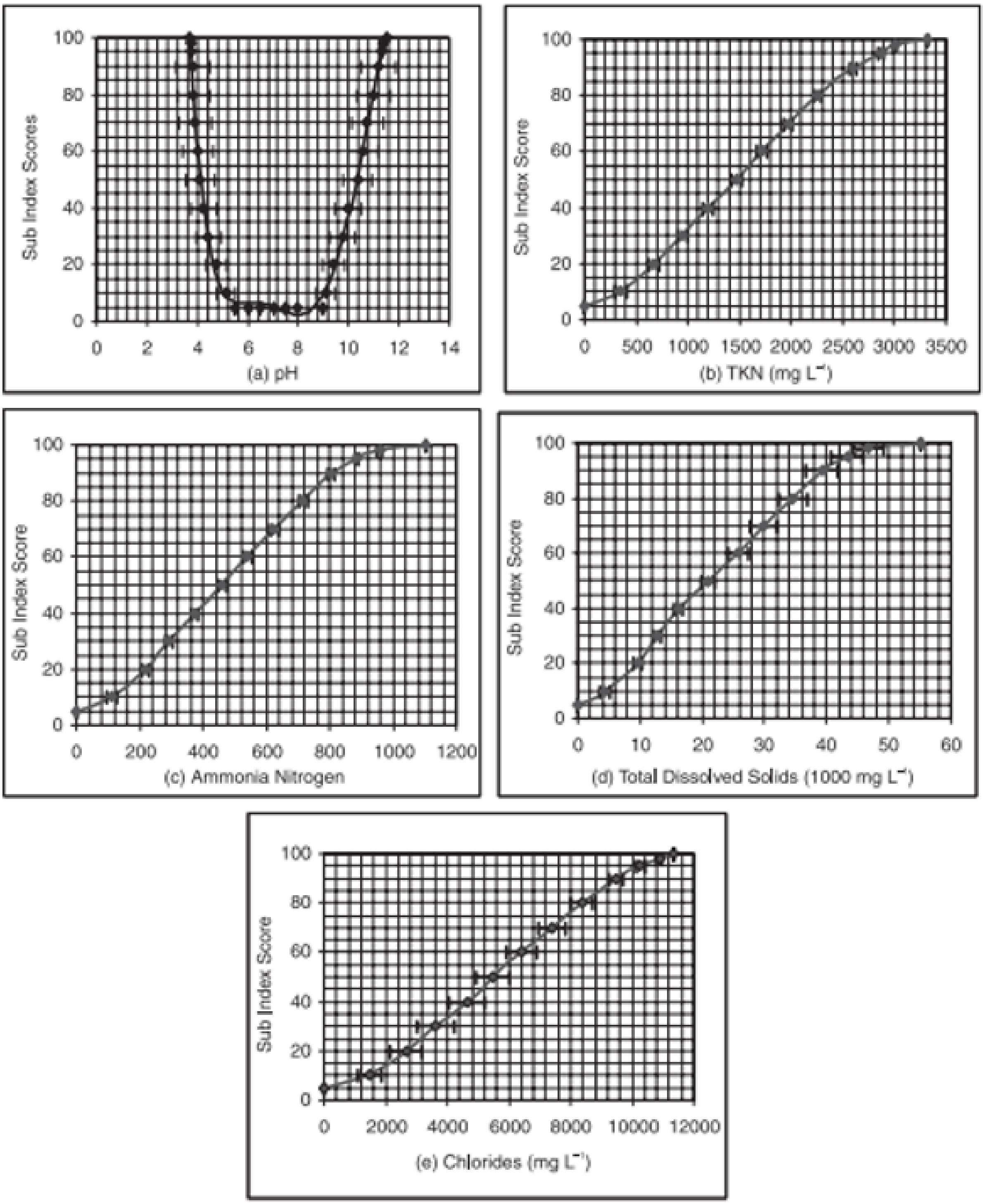
## Appendix 1




LPI organic ($LPI_{or}$) sub-index average curves with 90% confidence limit for (a) COD; (b) BOD5; (c) Phenolic Compounds; and (d) Total Coliform Bacteria

**Source: Kumar and Alappat (2005)**

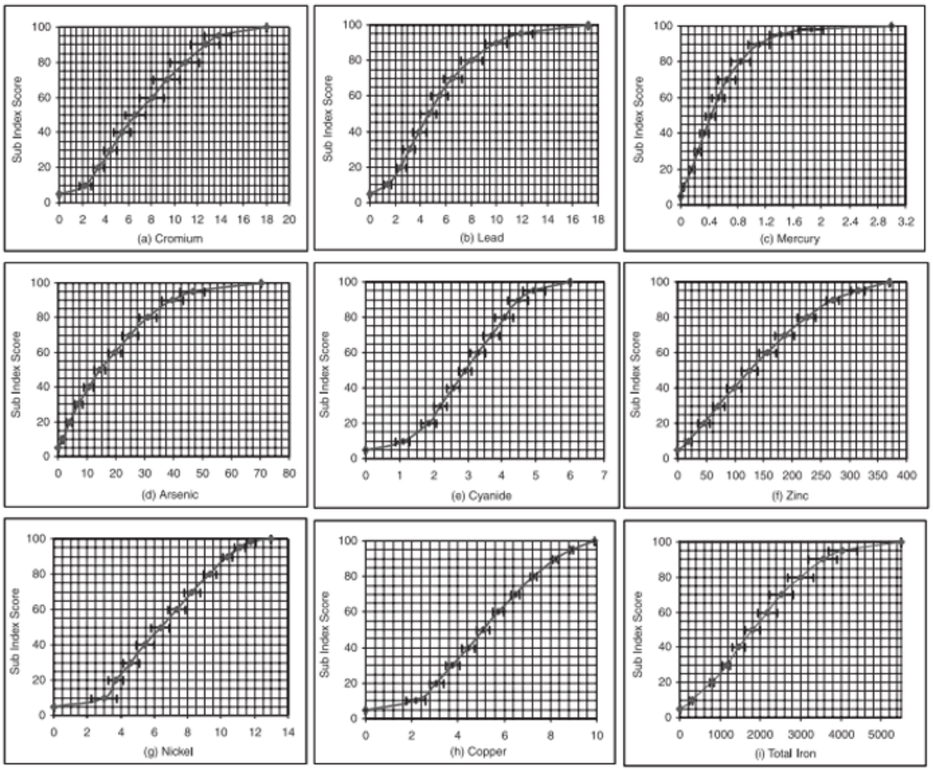
**Appendix 2**




LPI inorganic ($LPI_{in}$) sub-index average curves with 90% confidence limit for (a) pH; (b) TKN; (c) Ammonia Nitrogen; (d) Total Dissolved Solids; and € Chlorides

**Source: Kumar and Alappat (2005)**

## Appendix 3




Sub-index average curves with 90% confidence limit for (a) Chromium; (b) Lead; (c) Mercury; (d) Arsenic; (e) Cyanide; (f) Zinc; (g) Nickel; (h) Copper; and (i) Total Iron

**Source: Kumar and Alappat (2005)**

## Appendix 4

Leachate pollution index parameters with sub-index weight factor

| Sub-index | Parameters | Weight factor ($w_i$) |
|---|---|---|
| **LPI organic ($LPI_{or}$)** | COD | 0.267 |
| | BOD | 0.263 |
| | Phenolic compounds | 0.246 |
| | Total coliform bacteria | 0.224 |
| **LPI inorganic ($LPI_{in}$)** | pH | 0.214 |
| | TKN | 0.206 |
| | Ammonia nitrogen | 0.198 |
| | Total dissolved solids | 0.195 |
| | Chlorides | 0.187 |
| **LPI heavy metals ($LPI_{hm}$)** | Total chromium | 0.125 |
| | Lead | 0.123 |
| | Mercury | 0.121 |
| | Arsenic | 0.119 |
| | Cyanide | 0.114 |
| | Zinc | 0.110 |
| | Nickel | 0.102 |
| | Copper | 0.098 |
| | Iron | 0.088 |

Source: Kumar and Alappat (2005)