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Evaluation of landfill leachate treatment system using multivariate analysis

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ABSTRACT

In this study, selected physicochemical and heavy metal concentrations were identified and analyzed in leachate samples. The leachate samples were collected at four different stages namely; raw equalization pond (EqP), dissolved air floatation combined with coagulation (DAF1/coagulation), sequencing batch reactor (SBR), and dissolved air floatation combined with coagulation (DAF2/coagulation). For each stage, 19 parameters were tested covering 12 physiochemical parameters including pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), color, ammonical nitrogen (NH_3–N), total suspended solids (TSS), total dissolved solids (TDS), electrical conductivity (EC), total concentrations of sodium (Na), magnesium (Mg), and calcium (Ca) as well as the total concentrations of seven heavy metals involving iron (Fe), copper (Cu), cadmium (Cd), lead (Pb), manganese (Mn), nickel (Ni), and zinc (Zn). Identifying the characteristics of the four leachate samples from each stage was aided with three different statistical methods consisting of descriptive, factor, and cluster analyses. The results of factor analysis showed that 95.34% of the total variation in the selected parameters was explained by two factors and identified as the responsible factors. Cluster analysis exhibited that the four ponds entirely have different properties (EqP, DAF1, SBR, and DAF2). This study helps to evaluate and comprehend the behavior of the designated parameters and better understand their relationships with one another for more efficient, practical, and productive landfill leachate treatment and management.

Keywords: Physicochemical; Heavy metal; Leachate; Factor analysis; Cluster analysis

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1. Introduction

The exponential growth in Malaysia's population has absolutely led to a tremendous increase in the generation of municipal solid wastes (MSW). Based on the United Nations (UN) Revision of World Population Prospects 2019, Malaysia's population jumped from 25.69 M in 2005 up to 31.53 M in 2018. In synchronization with the figures released by the Solid Waste Management and Public Cleansing Corporation (SWCorp) in 2019 where the per capita generation of waste has doubled from 0.8 kg in 2005 to an average of 1.17 kg/person each day in 2018, the estimated annual rate is about 3.5% of waste generations in kg/cap/d. These statistical figures show a directly proportional relationship between the growth in population and waste generation per capita in Malaysia. Hence, Malaysia generates around 14.2 million tons of solid waste per year, which is equivalent to 1.2 kg/cap/d, that is, approximately

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38,850 tons/d. The Malaysian Department of Statistics estimates that the population in 2020 in particular, to grow up from 32.37 to 32.60 M. Therefore, the average amount of solid waste is expected to jump to 1.23 kg per capita/d, that is, approximately 40,100 tons/d by the end of 2020. The main fractions of MSW generated in Malaysia are 45% organic material, 13% plastics, and 9% paper [1]. However, the SWCorp director stated that there has been substantial growth in the collection of recycled items in 2020 in comparison with 2019. Furthermore, due to the current pandemic of Covid-19 and the implementation of the movement control order (MCO) in Malaysia that was enforced in March 2020 where most of the commercial and industrial sectors were closed, the amount of solid waste that was delivered to landfills plumped by 40% during the MCO [2].

For its low cost and simplicity, landfilling is preferred over many other high cost and complex methods such as incineration which made it a globally accepted method to dispose of solid wastes [3]. Despite landfilling has been favorably utilized as the main disposal method for MSW by the Malaysian Federal Government for being effectively simple, economical, and thus the most common technique so far, the substantial extremely polluted leachate of more than 3 million L/d has been of highly significant concern especially in such a tropical country as Malaysia attributed to a high amount of rainfall and MSW generated [4]. The total reported number of landfills in Malaysia is 296 where around 166 are reported to still be in service [5]. Most of the landfills in Malaysia are not yet equipped with effective systems of leachate treatment. Additionally, being located near rivers which are considered to be main Malaysia's source of water, landfills have unfortunately led to river water pollution besides other ground and surface water resources [6]. A total of 89% of the MSW generated in Malaysia ends up in the landfills with poor treatments in which only 1% of the overall incoming MSW undergoes proper treatments where half of the landfills in Malaysia are open dumping sites; 10% of the rest are sanitary landfills in which half of them are without a leachate treatment facility while the other with a leachate treatment plant [1].

Leachate is generated as water, that is, mainly rainfall penetrates through landfills. The interaction between rainfall and wastes produces leachate that contains a large amount of organic, non-organic, and other pollutants. As a matter of fact, leachate consists of higher loads of contaminates than that of raw sewage and some industrial effluents which could contain a large amount of biodegradable and non-biodegradable organic matter, inorganic salts, heavy metals, ammonia, phosphates, sulfides, and other toxins as well as its repulsive color and odor [3]. According to the United States Environmental Protection Agency (USEPA), landfill leachate may contain household hazardous contaminants originated from paints, batteries, cosmetics, pharmaceuticals, and cleaning chemicals besides bulky wastes such as household appliances and that one generated from construction sites. Thus, landfill leachate is a potential threat that could cause a destructive impact and severe damage to the environment and human health. The volume and the characteristics of leachate differ from one another dependent on so many factors such as the location, weather, composition of MSW, landfilling practice and handling, landfill design, and structure besides the age of the landfill [4].

A typical landfill goes through three main different phases of decomposition namely; aerobic, initial anaerobic, and final anaerobic phases. As soon as wastes are buried and compacted, the landfill wastes undergo aerobic decomposition. According to Kjeldsen et al. [7], this phase usually lasts for a few days which is governed by the depletion of oxygen. Therefore, the anaerobic phase starts to establish. In the initial phase of anaerobic decomposition, complex organic compounds are decomposed by a hydrolytic-type of bacteria to a simpler soluble organic form and then fermented by the acidic bacteria to produce acidic products mainly volatile fatty acids, that is, a short carbon chain of carboxylic acids which result in acidic leachate that increases the solubility of many substances including heavy metals. Then, it is followed by the acetogenesis process where acetate and carbon dioxide are formed. Generally, the leachate in this phase is reported to contain the highest concentrations of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) [7]. As the landfill wastes reach the third phase, that is, the final anaerobic phase in which methanogenic bacteria typically come last, the pH starts to increase as acids are consumed and converted mainly into methane and carbon dioxide. In this phase, the biodegradability of the organic matter plumps resulting in old leachate containing more refractory and xenobiotic organic matter such as humic-like substances and pesticides and inorganic compounds such as ammonia than the young leachate [8].

Determination and evaluation of the quality of the leachate are significant to evaluate the risk of high concentrated organics, non-organics, heavy metals, and hazardous parameters and their effect on public health and the environment, as well as to help for selecting the best way for leachate treatment, discharge, and management [9]. Leachate could be treated in several ways physically, biologically, and/or chemically to minimize the amount of pollutants. Upon discharging into watercourses such as rivers, leachate has to comply with the discharge limits according to Regulations 2009, Environmental Quality Act (EQA), 1974 for the acceptable conditions for discharge of leachate set by the Department of Environment (DOE), Malaysia. The selection of the treatment method is highly governed by the characteristics of the leachate to be treated. Conventionally, most sanitary landfill leachate treatments in Malaysia, if not all, employ a biological treatment such as aerobic, semi-aerobic, and anaerobic digestion systems as the heart of the treatment processes. These biological techniques are considered to be the most suitable treatment of young leachate that contains a high BOD concentration. However, pre-treatments commonly exist alongside the biological treatment to further facilitate and enhance the pollutants removal efficiency especially for stabilized leachate. Tertiary treatments, often to be chemical and/or physical processes, are also being utilized in some landfill leachate treatment plants. Polishing the effluent prior to the discharge is usually applied after the tertiary treatment if it happens to be a chemical type of treatment. Since the BOD/COD ratio of old/stabilized leachate is low, a biological treatment alone will not be sufficient for the leachate treatment. Hence, an integrated treatment of old leachate is required. Common typical physicochemical treatment methods such as coagulation–flocculation, chemical precipitation, adsorption, advanced oxidation processes (AOPs), filtration, and dissolved air floatation (DAF) systems have been proven to be effective in treating complex pollutants found in old leachate, particularly [10,11].

Various multivariate statistical methods have been employed to evaluate the performance of different environmental issues or to be used for comparison and other purposes that have several variables measured from each sample [12–15]. Factor analysis and cluster analysis has become an important and adequate statistical tool to investigate the principles of interaction of environmental components in the life sciences and their integration [16]. Cluster analysis is a multivariate method used to sort the observations of the system into groups called clusters using similarities between various observations as a criterion in the same group [17]. In literature, several studies recently reported the application and use of multivariate analysis for the assessment of natural water and air quality. Alkarkhi et al. [18] employed factor analysis for the quality assessment of surface water. Mohamed et al. [19] used multivariate analysis for the assessment of river water quality in Malaysia. Hamzah et al. [20] utilized multivariate Analysis for the assessment of physical and chemical parameters of Marine Water Quality. Yusup et al. [21] used factor analysis for the assessment of particulate matter (PM) and its metal content. Yusup et al. [22] employed multivariate analysis to assess the effects of microclimate variables on carbon dioxide flux at the tropical coastal ocean in the China Sea. Alkarkhi et al. [18] utilized multivariate analysis for heavy metals assessment in sediments of selected estuaries of Malaysia. However, the employment of multivariate analysis to assess the parameters in leachate treatment and its differentiation in different treatment processes has not been well-investigated. The objectives of this work are: (1) to evaluate the performance of the three treatment stages for landfill leachate including dissolved air floatation combined with coagulation (DAF1/coagulation), sequencing batch reactor (SBR), and dissolved air floatation combined with coagulation (DAF2/coagulation), (2) to identify the source of differences in concentration of the selected 19 parameters regarding the raw leachate and different treatment processes applied, this objective can be achieved by using factor analysis, and (3) to investigate the similarity and dissimilarities between different treatment processes applied and the raw leachate using cluster analysis.

2. Materials and methods

2.1. Sampling and site characteristics

All leachate samples in this study were collected from the Sungai Udang Sanitary Landfill (SUSL) site where located in the coastal city of Sungai Udang, Central Malacca district, about 3 km to the northeast of Sungai Udang town and around 9 km west to the Straits of Malacca, Malaysia. The landfill is situated on the borderline between Central Malacca and Alor Gajah districts and is bounded by housing areas and some factories. SUSL was operated by SWM Environment Sdn. Bhd. until it has been taken over by GreenViro Solutions Sdn. Bhd in 2020. SUSL is the only sanitary landfill that is still operating in Malacca which has a land area of 26 ha. According to Murali [23], SUSL has started to operate since the end of 2014 after the closure of the landfill site at Kurbong, receiving more than 20,000 tons of garbage each month including bulk wastes whose third cell is estimated to last until 2023. SUSL is equipped with a landfill leachate treatment facility. According to the former operator of SUSL, the landfill has a landfill capacity of more than 700,000 tons of waste and a capacity of a leachate treatment plant of about 200 m^3/d with a gas venting system. It has been reported that SUSL is going to be the first sanitary landfill to adopt the waste-to-energy (WTE) system upon the recent visit by the Minister of Housing and Local Government of Malaysia [24]. The raw leachate influent from the equalization pond (EqP) in the SUSL treatment plant is primarily treated via a dissolved air floatation (DAF1) system incorporated with a coagulation and flocculation process. The primary effluent is discharged into a balancing tank (BT) and then pumped into the SBR. Next, the secondary effluent is pumped into a dissolved air floatation feed pond (DFP) prior to the treatment via DAF2 system. The tertiary effluent is then pumped into a clean water tank (CWT). Lastly, the tertiary effluent is further polished via a carbon and sand filtration system and then discharged into watercourses as final treated effluent. Leachate samples were collected three times during the period between September to October 2020 from four different stages of the SUSL leachate treatment plant namely; EqP as raw leachate influent, BT as primary/DAF1 effluent, DFP as secondary/SBR effluent, and CWT as tertiary/DAF2 effluent. Individual samples were manually collected over a period of time less than 15 min from each stage. They were collected by a 500 mL-sampling rod at a depth of 0.3 m and then transferred into high-density polyethylene (HDPL) 5 L containers separately which have been washed with detergent and rinsed with deionized water (DIW) several times prior to the collection. For total metals analysis, 500 mL of each sample was transferred to one liter HDPE bottles that have been prewashed with detergent and 1:1 HNO_3 in order to prevent any possible sorption through the wall of the container and to remove any contaminants and impurities that one way or another could interfere or cause clogging during the analysis of metals. Then, they were rinsed with DIW several times. All of the samples were immediately placed into approximately 5°C–4°C Styrofoam icebox, transported to the laboratory, and cooled at 4°C in the fridge to minimize any further biological and chemical reactions.

2.2. Analytical study

In this study, 19 parameters were analyzed according to the standard methods for the examination of water and wastewater (APHA) and methods for chemical analysis of water and wastes (USEPA). Leachate samples were stirred thoroughly prior to every analysis in which each parameter was analyzed five times. pH and dissolved oxygen (DO) were measured in situ via portable digital pH meter and YSI 5000 DO meter; respectively. BOD_5 was measured according to method 5210 B [25] without seeding. All BOD bottles were pre-sterilized with 10% HCl, left overnight, and rinsed with DIW several times prior to the test. Needed nutrients pillow packets provided by HACH were added just before the analysis to the dilution water that was incubated at 20°C overnight. HACH DR/2800 spectrophotometer (Loveland, Colorado, United States) was used to determine the concentrations of COD, true color, ammonia nitrogen (NH_3–N), and total suspended solids (TSS). COD was measured by method 8000, a reactor digestion method at a wavelength of 620 nm. True color was determined by method 8025 at 455 nm. NH_3–N was tested by method 8155, a salicylate method at 655 nm. TSS was measured by method 8006, a photometric method at 810 nm. Total dissolved solids (TDS) and electrical conductivity (EC) were determined by portable electric conductivity meter, Mettler Toledo FE30 FiveEasy benchtop conductivity meter. As for the analysis of metals and heavy metals, it was analyzed by method 200.2 [26] and determined using a flame atomic absorption spectrometer (FAAS). In this method, HNO_3 was used for its instrumental compatibility and the high solubility of their nitrate salts in water.

2.3. Statistical analysis

Statistical analysis such as descriptive statistics, factor analysis, and cluster analysis were used to analyze the data for physicochemical and heavy metal parameters. Factor analysis (FA) is a data reduction technique that suggests how many factors form as a combination of selected parameters are important to explain the observed variances in the data [21,27]. Cluster analysis (CA) is a multivariate technique, whose primary purpose of cluster analysis (CA) is to classify the observations into groups or clusters based on their similarities, where the objective is to find an optimal grouping for which the observations within each cluster are similar, but the clusters are dissimilar to each other. Hierarchical clustering is the most common approach in which clusters are formed sequentially [15,27].

3. Results and discussion

3.1. Descriptive statistics

The collected samples from different ponds of landfill leachate treatment systems were analyzed for physicochemical and heavy metals concentrations in leachate. Descriptive statistics for the concentration of heavy metals and physicochemical parameters in each stage of the landfill leachate treatment system are presented in Table 1. It can be observed that the highest and lowest average of physicochemical and heavy metals varies among landfill stages which considered as an indication of the change in the properties or the behavior of selected parameters that influenced by the treatment of the landfill leachate at different stages of the landfill leachate treatment plant as shown in Fig. 1; from the EqP as raw leachate influent, after dissolved air floatation (DAF1) system, the SBR followed by DAF2 system. Furthermore, Table 1 shows that the highest average value for the selected physicochemical and heavy metal parameters was noticed in raw leachate effluent except for the pH in which the highest average was observed in the primary effluent and the lowest value was observed in the tertiary effluent except for the concentrations of Na, Ca, Mg, Cd, and Ni in which their relatively lowest values were observed in the secondary effluent.

According to the acceptable conditions for the discharge of leachate based on the second schedule, regulation 13 under the Malaysian EQA [28] as well as the World Health Organization/Food and Agriculture Organization (WHO/FAO) standards [4,29,30], the physicochemical parameters and heavy metals concentrations for each sample were investigated whether within or outside the permissible limits in reference to Table 1. For the raw leachate influent, it was observed that all analyzed physiochemical parameters and heavy metals were outside the permissible limits except for pH and the concentrations of Na, Ca, Mg, and Zn. As for the pH and the concentrations of Na, Ca, Mg, Zn, Fe, and Cu of the primary effluent, they were within the permissible limits while the concentrations of Pb and Mn were slightly higher than the discharge limits. The average values of BOD and COD of the raw leachate sample as presented in Table 1 were found to be 696 and 4,580 mg/L, respectively, with a biodegradability ratio of (BOD_5/COD) = 0.15, which means that the landfill is relatively old and the leachate is stabilized [29]. Although the parameters in DAF1 effluent were reported with lower values compared with raw leachate, however, the level for most parameters is still higher than acceptable discharge limits. This result is in the agreement with several studies

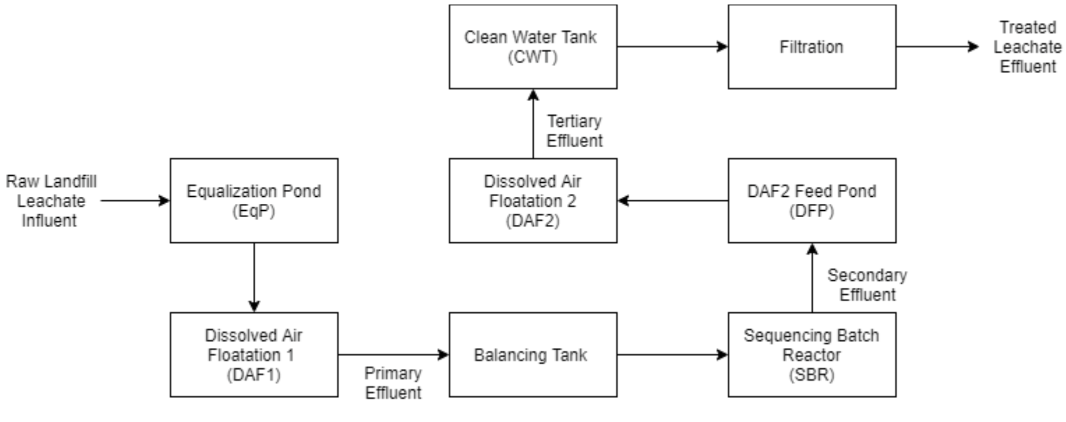

Fig. 1. Block diagram of the landfill leachate treatment facility in SUSL.png.

Table 1
Descriptive statistics for the measured parameter including the mean and standard deviation

	Raw leachate influent	Primary/DAF1 effluent	Secondary/SBR effluent	Tertiary/DAF2 effluent	Std limit
pH	8.22 ± 0.03	8.56 ± 0.02	7.43 ± 0.12	5.73 ± 0.03	6–9*
DO	0.05 ± 0.01	7.04 ± 0.01	10.99 ± 0.07	7.32 ± 0.01	>5**
BOD$_5$	695.8 ± 25.06	171.7 ± 1.53	13.3 ± 1.15	3.5 ± 0.71	20*
COD	4,580 ± 178.89	2,400 ± 70.71	420.4 ± 3.85	248.6 ± 0.89	400*
Color	14,900 ± 324.04	6,080 ± 294.96	1,856 ± 30.5	568 ± 19.24	100*
NH$_3$-N	1,820 ± 148.32	1,520 ± 44.72	10.2 ± 0.45	5.8 ± 0.45	5*
TSS	198.4 ± 13.69	137.8 ± 0.84	37.8 ± 0.84	9.4 ± 0.89	50*
TDS	7,934 ± 36.47	4,542 ± 21.68	1,761.8 ± 2.49	1,335.4 ± 1.34	500–1,000**
EC	17,942 ± 24.9	10,078 ± 33.47	3,916 ± 5.48	2,964 ± 5.48	1,500**
Na	7.69 ± 0.44	3.72 ± 0.14	4.05 ± 0.12	6.35 ± 0.37	200**
Ca	31.24 ± 0.42	20.51 ± 0.29	22.81 ± 0.27	25.01 ± 0.39	100**
Mg	3.86 ± 0.05	1.97 ± 0.03	1.92 ± 0.05	3.26 ± 0.03	200**
Fe	6.52 ± 0.15	4.39 ± 0.15	2.64 ± 0.07	2.57 ± 0.14	5.0*
Cu	0.52 ± 0.01	0.17 ± 0.0	0.06 ± 0.0	0.03 ± 0.0	0.20*
Cd	0.07 ± 0.01	0.05 ± 0.0	0.04 ± 0.0	0.05 ± 0.0	0.01*
Pb	0.28 ± 0.03	0.13 ± 0.02	0.06 ± 0.02	0 ± 0.0	0.10*
Mn	0.33 ± 0.05	0.21 ± 0.01	0.08 ± 0.02	0.05 ± 0.0	0.20*
Ni	2.59 ± 0.20	1.75 ± 0.14	1.39 ± 0.09	1.65 ± 0.16	0.2*
Zn	0.32 ± 0.01	0.27 ± 0.0	0.08 ± 0.0	0.05 ± 0.0	2.0*

Other than pH, all units are in mg/L except for color, Pt-Co, and EC, μS/cm.
*Based on the second schedule, regulation 13 under Malaysian Environmental Quality Act (MEQA) discharge limits for landfill leachate.
**According to the World Health Organization/Food and Agriculture Organization (WHO/FAO) standards for the discharge of landfill leachate.

that reported the performance of physiochemical/coagulation processes for raw leachate treatment, although their process has reported significant removal for some parameters in raw leachate, however, the concentration of the parameters in their final effluent is still higher than the acceptable discharge limits [31,32], and further advanced of polishing treatment is required. The parameters of SBR effluent were reported within the permissible limits in which they were widened to include all but color, ammonia, TDS, EC, and the concentrations of Ni. Whereas, the COD and Cd concentrations were slightly higher than the standard discharge limits. The concentration of the most parameters after the biological treatment showed a significant reduction of the pollutants residuals in the effluent where around 63% of the analyzed parameters were within the permissible limits. Lastly, the parameters of the DAF2 effluent – which is considered to be a further treatment prior to the polishing stage in the SUSL leachate treatment plant – were all within the permissible limits excluding color, TDS, EC, Cd, and Ni. Besides, the concentration of ammonia was marginally higher than the discharge limits while the pH was slightly lower. For instance, the average concentration of ammonia of the tertiary effluent was reported to be 5.8 mg/L while the permissible limit is 5.0 mg/L. It is believed that the carbon and sand filtration technique employed as a polishing stage after the tertiary treatment in SUSL would include the pH and the concentration of ammonia of the final effluent within the limits permissibility of the leachate discharge and perhaps the rest of the parameters of the tertiary effluent that did not meet the MEQA discharge limits including color, Cd, and Ni.

According to a study conducted by Abu Amr et al.[29]; the average of two samples collected from SUSL within March and June, the COD and BOD were reported to be 2,300 and 110 mg/L, respectively. In other words, the ratio of BOD$_5$/COD of 0.05 indicates that the age of the wastes from which the samples of leachate generated is considered to be old. In the same study, Abu Amr et al. [29] reported a high pH of 8.6 representing a stabilized leachate as acids are rapidly consumed mainly carboxylic acids in which a condition of anaerobic system of methanogenic phase in the cell was presumably reached which is considered to be the fourth phase of decomposition that generally landfills acceptably undergo after the initial aerobic phase, anaerobic acid phase and initial methanogenic phase [7]. As a comparison to the studied raw leachate sample collected from SUSL, characteristics of raw leachate generated from some other landfills in Malaysia are summarized in Table 2.

3.2. Factor analysis

The data for physicochemical and heavy metals were further analyzed to identify the source of the differences between different ponds. Factor analysis was used to identify the source of variation in the data. The analysis was performed using the data set for correlation matrix including 19 parameters (variable), the analysis showed

Table 2
Characteristics of raw leachate from some landfill sites in Malaysia compared to the current analyzed raw leachate from SUSL

Selected parameter	Unit	SUSL, Melaka[a]	APLS, Perak[b]	SRLS, Johor[c]	ATCL, Selangor[d]	PBLS, Penang[e]	KLS, Kedah[e]
pH	–	8.22	8.13	8.46	7.95	8.36	8.02
DO	mg/L	0.05	0.85	–	6.71	–	–
BOD_5	mg/L	696	196	140	62	181	285
COD	mg/L	4,580	3,852	2,343	907	1,819	1,295
BOD_5/COD	–	0.15	0.05	0.07	0.07	0.1	0.2
NH_3–N	mg/L	1,820	1,241	558	750	1,627	562
Color	Pt-Co	14,900	14,984	4,555	2,527	3,615	3,029
TSS	mg/L	198.4	–	225	1,570	815	553
TDS	mg/L	7,934	6,237	4,231	6,740	15.26*	4.17*
EC	µS/cm	17,942	–	7,858	9,100	22,360	7,660
Na	mg/L	7.69	–	–	–	–	–
Ca	mg/L	31.24	–	–	8.59	1,148.9**	1,498.9**
Mg	mg/L	3.86	–	–	2.85	410***	271.1***
Fe	mg/L	6.52	–	7.97	1.25	4.9	3.82
Cu	mg/L	0.52	–	–	0.004	–	–
Cd	mg/L	0.07	–	–	0.003	–	–
Pb	mg/L	0.28	–	0.08	0.002	–	–
Mn	mg/L	0.33	–	–	0.03	–	–
Ni	mg/L	2.59	–	–	–	–	–
Zn	mg/L	0.32	–	–	0.03	0.52	0.33

All values are averaged.
All mean non-metals values were rounded up to the nearest whole number.
*(%); **(mg/L Ca-$CaCO_3$); ***(mg/L Mg-$MgCO_3$).
[a]Current study; [b]Zakaria and Aziz [5]; [c]Mohd-Salleh et al. [33]; [d]Banch et al. [34]; [e]Aziz et al. [35].

that 19 factors can be extracted with the standard deviation, the proportion of variance accounted, and cumulative proportion of variance for the extracted factors (Table 3). The variances explained by each component are presented in a Scree plot (Fig. 2). Only two factors with a standard deviation greater than 1 (Table 3) can be selected explaining 95.34% of the total variance in the physicochemical and heavy metals parameters (standard deviation in factor analysis is a measure of the significance of the factors). The parameter loadings for the two factors are presented in Eqs. (1) and (2), illustrate that most of the variables associated with each factor are well-defined and contribute slightly to another factor, which helps in the interpretation of the result, loading of more than 0.70 is considered a strong correlation and contributes significantly in explaining the total variation.

$$F_1 = 0.94\text{pH} - 0.82\text{DO} + 0.73\text{BOD}_5 + 0.90\text{COD} + 0.87\text{color} + 0.95\text{NH}_3 - \text{N} + 0.96\text{TSS} + 0.81\text{TDS} + 0.80\text{EC} + 0.08\text{Na} + 0.28\text{Ca} + 0.09\text{Mg} + 0.89\text{Fe} + 0.81\text{Cu} + 0.50\text{Cd} + 0.89\text{Pb} + 0.91\text{Mn} + 0.66\text{Ni} + 0.97\text{Zn} \quad (1)$$

$$F_2 = -0.31\text{pH} - 0.19\text{DO} + 0.62\text{BOD}_5 + 0.42\text{COD} + 0.50\text{color} + 0.17\text{NH}_3 - \text{N} + 0.24\text{TSS} + 0.56\text{TDS} + 0.57\text{EC} + 0.98\text{Na} + 0.94\text{Ca} + 0.98\text{Mg} + 0.45\text{Fe} + 0.57\text{Cu} + 0.79\text{Cd} + 0.40\text{Pb} + 0.34\text{Mn} + 0.68\text{Ni} + 0.17\text{Zn} \quad (2)$$

The first factor accounted for 79.41% (Table 3) of the total variance was negatively correlated with DO and positively correlated with other parameters. Five parameters (Na, Ca, Mg, and Cd) contribute significantly to this factor. The selected parameters could be categorized into dissolved organic matter involves BOD and COD, inorganic compounds consist of ammonia, Na, Ca, and Mg while heavy metals comprise Fe, Cu, Cd, Pb, Mn, Ni, and Zn. All of which have a direct impact on the other physiochemical parameters which are made up of pH, DO, TSS, TDS, and EC. As for the abundant presence of ammonia, it mainly originates from the biological decomposition of organic matter in the landfill besides some ammonia-household containing wastes such as cleaning products as well as from nitrogen-nutrients found in the wastes or embedded in the landfill soils that through mineralization, it converts into ammonia. Moreover, not neglecting the fact that rainwater as a mixed electrolyte [30] could somehow contribute to the concentrations of ammonia as well as Na, Ca, and Mg when percolating into the landfill. Wastes of highly nutritional food such as vegetables and their peels [33] might also contribute to the concentrations of such minerals. As for heavy metals, it mainly comes from metal scraps, electric and electronic components, and household appliances that have been disposed of in the landfill apart from many various sources such as soil and air containing heavy metals that leached by rain into the landfill. It was reported that the presence of Fe and Mn comes from steel scrap disposed of in the landfill, Cu content might be due to dumping some blades and paints [34] as well as coil wires and some construction wastes. Zn and Ni are associated with the disposal of batteries and Pb comes from discarding various types of pipes and plastics [35,36]. Moreover, Cd content could be coming from plastics, steel coatings and Ni–Cd batteries.

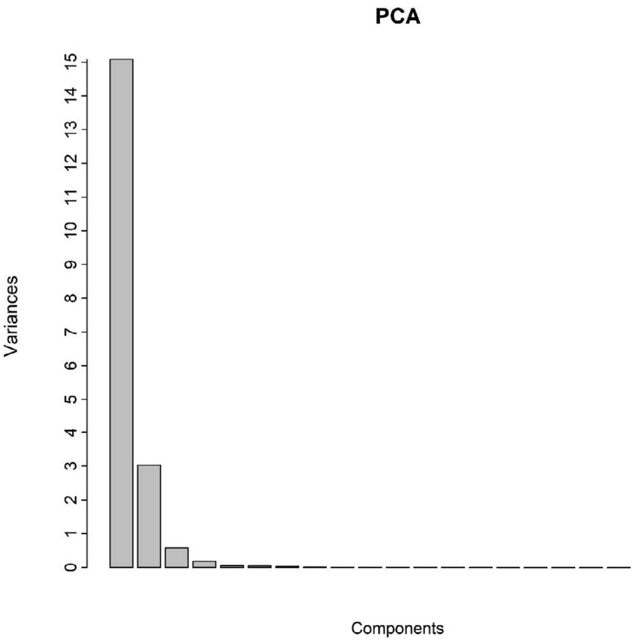

Fig. 2. Scree plot showing the eigen-values for each extracted component.

The second factor, on the other hand, accounted for 15.93% (Table 3) of the total variance was negatively correlated with pH and positively correlated with others. Five parameters (Na, Ca, Mg, and Cd) contribute significantly to this factor. The positive contribution of these parameters is attributed to the lower pH value (5.7) which may increase the solubility of these metals in the solution and reduce the settling efficiency. The relationship between the pH and heavy metals solubility was evaluated by Rothe et al. [37]. The study evaluated the effect of pH variation on the solubility of Zn^{2+}, Cd^{2+}, Cu^{2+}, Pb^{2+}, and Cr^{2+} in sewage sludge. The study concluded that the metal solubility will be increased at pH lower than 7 and reduced at pH between 7–10, while the solubility of heavy metals in wastewater is increased at a low pH value and reduced when pH increased higher than 7.

The relationship between the values of extracted factors and the samples from different ponds (stage) was studied to understand the behavior of selected parameters in each pond. The values of the first factor for different samples obtained from different ponds are presented in Fig. 3, it can be seen that the behavior of various samples is changed with the first factor since the EqP as raw leachate influent and DAF1 ponds showed positive contribution while SBR and DAF2 ponds showed negative contribution. The positive contribution was due to a high concentration of parameters with positive loadings and the negative contribution was due to a high

Table 3
Showing the standard deviation for each component, proportion of variance, and cumulative proportion

Importance of components					
	Comp.1	Comp.2	Comp.3	Comp.4	Comp.5
Standard deviation	3.8842431	1.7396597	0.75676514	0.41934534	0.217312773
Proportion of variance	0.7940708	0.1592850	0.03014176	0.00925529	0.002485518
Cumulative proportion	0.7940708	0.9533558	0.98349756	0.99275285	0.995238368
	Comp.6	Comp.7	Comp.8	Comp.9	
Standard deviation	0.207469708	0.164763425	0.0841863842	0.0711217779	
Proportion of variance	0.002265457	0.001428789	0.0003730183	0.0002662267	
Cumulative proportion	0.997503825	0.998932613	0.9993056316	0.9995718583	
	Comp.10	Comp.11	Comp.12	Comp.13	
Standard deviation	0.0583457669	0.0452762515	3.581582e-02	3.119786e-02	
Proportion of variance	0.0001791699	0.0001078915	6.751437e-05	5.122665e-05	
Cumulative proportion	0.9997510282	0.9998589198	9.999264e-01	9.999777e-01	
	Comp.14	Comp.15	Comp.16	Comp.17	
Standard deviation	1.861939e-02	6.569538e-03	4.791016e-03	3.337161e-03	
Proportion of variance	1.824641e-05	2.271517e-06	1.208097e-06	5.861390e-07	
Cumulative proportion	9.999959e-01	9.999982e-01	9.999994e-01	1.000000e + 00	
	Comp.18	Comp.19			
Standard deviation	6.681153e-04	2.606402e-04			
Proportion of variance	2.349358e-08	3.575437e-09			
Cumulative proportion	1.000000e + 00	1.000000e + 00			

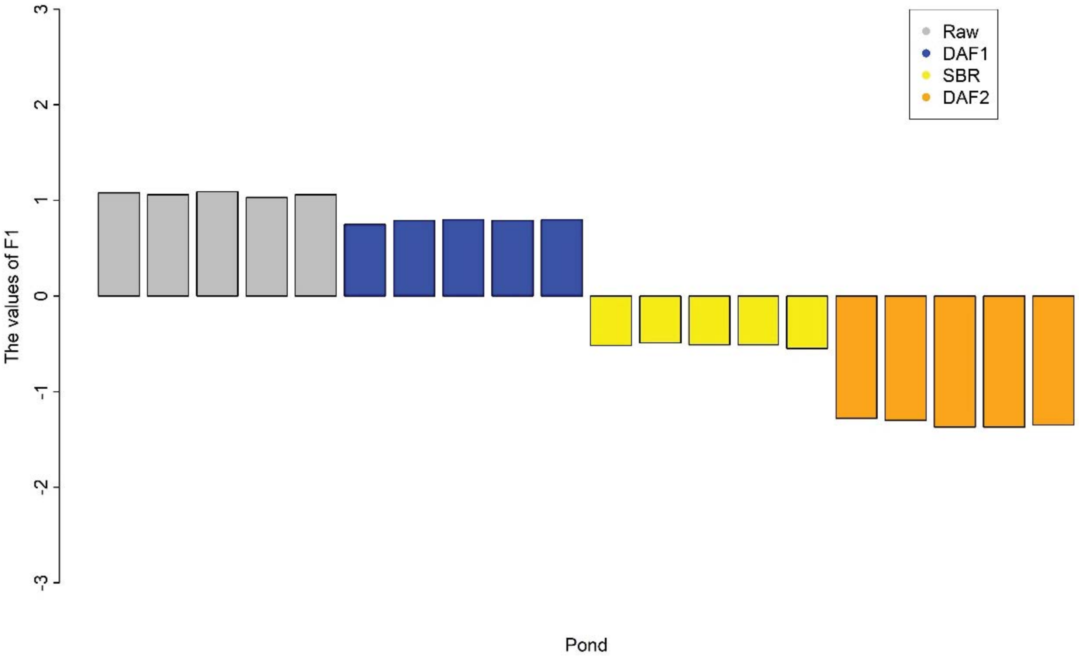

Fig. 3. Showing the behavior of the selected parameters to the first factor through various ponds.

concentration of parameters with negative loadings (here is only DO). The DO concentration in raw leachate was too low due to earlier depletion of DO in the initial phase of aerobic digestion of high biodegradable organic fraction in leachate. The positive contribution was due to the high concentration of Na, Ca, Mg, and Cd while the negative contribution was due to the low concentration of these parameters (Fig. 4). The negative contribution of these parameters may attribute to the significant removal of the parameters during SBR and DAF2 processes. Several researchers reported significant removal of heavy metals and trace elements from leachate using different coagulation and biological processes [4,31,32]. The high and black colored leachate is highly reasoned by the high concentration of humic-like substances that either originated within the landfill or from the soil. They are derivative products of decomposed organic material in which they are soluble in basic medium whereas insoluble in acidic [38]. Being humic-like substances found in leachate are recalcitrant that is slowly or non-biodegradable organic matter in which mostly coupled to COD present in the leachate [7] and the pH of the raw leachate was high, that is, basic, that might have contributed to the degree of the leachate color that was found to be high and depicted in black [39]. The concentration of heavy metals in methanogenic phase leachate may not be a good representative of the actual concentrations or presence of the heavy metals found in the wastes. It is believed that the high pH value of the raw leachate resulted in lower heavy metal concentrations detected due to precipitation or sorption of these heavy metals which might affect the COD results. The solubility of heavy metals in wastewater was found to be low when the pH is more than 7 promoting precipitation [4] as well as the sorptive capacity increases [7]. The concentrations of the parameters of the primary effluent showed an effective removal efficiency of pollutants deploying DAF/coagulation-flocculation process. Yet, the concentrations of the primary treated effluent parameters were still higher than the standard discharge limits. As for the pH and DO, however, the pH in DAF2 and SBR was lower than that in the raw influent. It could be due to the reduction in some cations and anions under the effect of two treatment processes. Abu Tawila et al. [40] reported significant removal for heavy metals as well as cations and anions using biofloculant of industrial wastewater, the study reported a slight reduction in pH at the final effluent. Where the higher DO value is attributed to the excess amount of oxygen supplied during the DAF system. Besides, the pH-dependent-DAF2/coagulation–flocculation process might cause a drop in the pH of the tertiary effluent. Most of the other pollutants in this effluent were further decreased to meet the standard discharge limits. For the concentrations of metals and heavy metals, it was observed that some further decreased such as Fe, Cu, Pb, Mn, and Zn while others increased such as Na, Ca, Mg, Ni, and Cd in a marginal manner. This could be attributed to several factors and reasons. For example, the DAF2 system is not covered, unlike the DFA1 system in which showed a noticeable decrease in the late concentrations. This causes the system to be more susceptible to foreign impurities affecting and overwhelming the removal efficiency of the system; mainly rain and acidic rain in an aggressive manner. The acidity of the medium also causes some mobility of the metals in general as well as leaching out either within the system or outside such as piping and fittings.

The values of the first and second factors are presented in a scatter diagram (Fig. 5), it can be seen that the four ponds are entirely different based on the selected parameters which indicate the properties of each pond is different, and the parameters behave differently.

In summary, it can be said that the behavior of selected parameters is totally different from one pond to another.

3.3. Cluster analysis

The relationship between the four ponds of the landfill leachate and source identification was investigated employing cluster analysis (CA) to identify the similarity and dissimilarity between the four ponds. CA was performed using the selected parameters including physicochemical and heavy metals parameters (19 parameters). The results of cluster analysis are presented in a pictorial form called a dendrogram as presented in Fig. 6 from EqP as raw leachate influent, BT as primary/DAF1 effluent, DFP as secondary/SBR effluent, and CWT as tertiary/DAF2 effluent.

It can be seen that cluster analysis exhibited a clear structure, showing each pond has a different concentration of the selected variables. CA resulted in four clusters each cluster represents a pond. Furthermore, Fig. 6 shows that the high dissimilarity between the four stages in the leachate treatment system.

The dissimilarity between the raw leachate influent and the other primary, secondary, and tertiary effluents are due

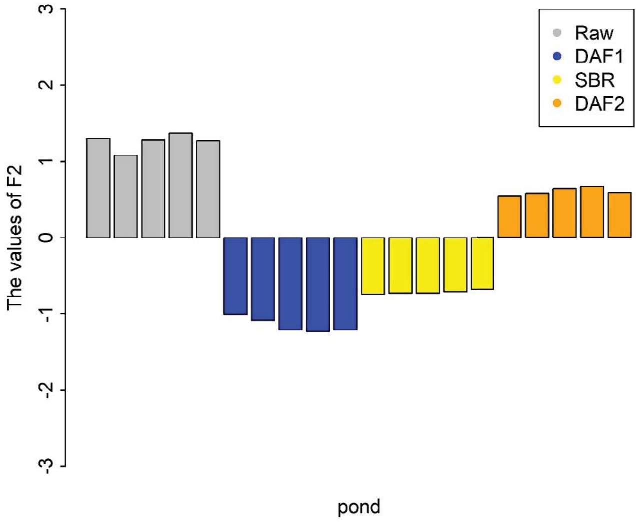

Fig. 4. Showing the behavior of the selected parameters to the second factor through various ponds.

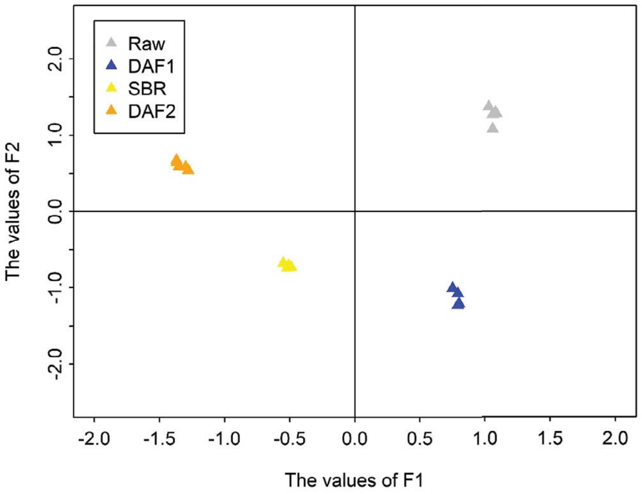

Fig. 5. Showing the behavior of the selected parameters to first and second factors through various ponds.

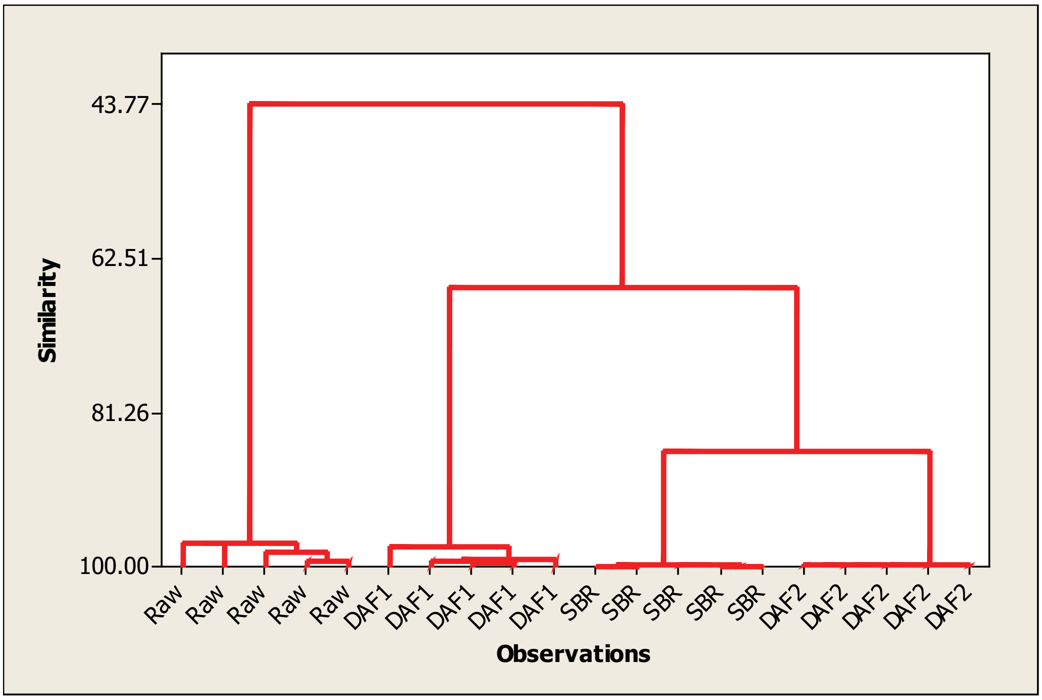

Fig. 6. Dendrogram showing the ponds according to physicochemical and heavy metals selected.

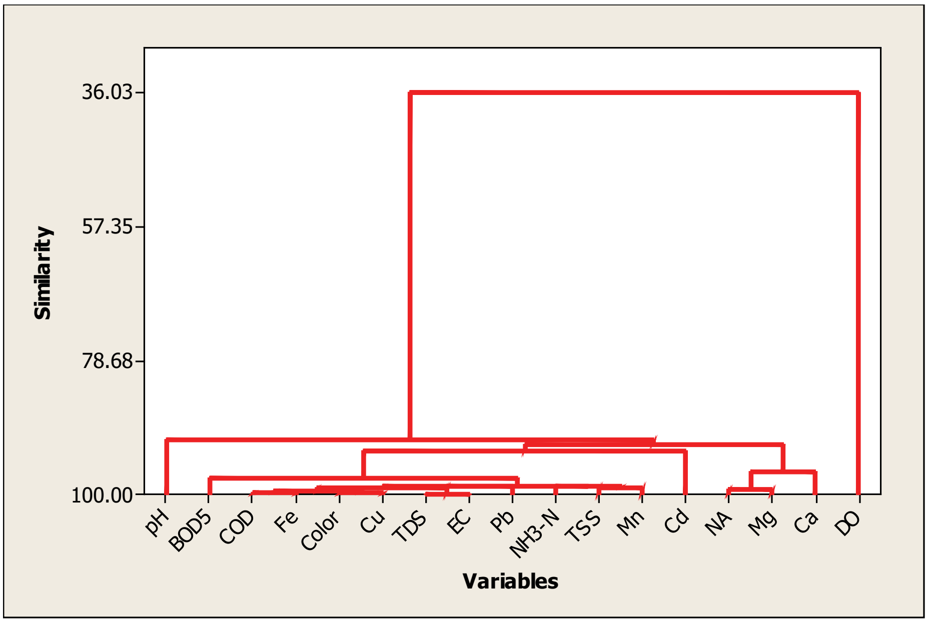

Fig. 7. Dendrogram showing the variables through various ponds.

to the effectiveness of the physical–chemical treatments employed in both DAF1 and DAF2 in which dissolved air is pumped to create micro-bubbles along with injecting certain coagulants and flocculants to remove and reduce contaminates level as well as the biological treatment done by SBR where aerobic decomposition of pollutants is engaged. It is clearly presented that the high dissimilarity is due to the efficiency and the significant effect of DAF 1, SBR, and DAF2 on the quality of leachate, respectively. Moreover, the results of CA revealed that the treatment processes in the leachate system are arranged in the correct sequential order as the reduction in the most 19 parameters is clearly presented during the three processes respectively. These serial leachate treatment techniques resulted in potent removal efficiency of pollutants in which most of the parameters have met the standard discharge limits of MEQA exclusively. Table 4 summarizes the pollutants removal efficiency of each treatment for selected parameters in this

Table 4
Treatment efficiencies of DAF1, SBR, and DAF2 in the SUSL treatment plant

Parameter	Treatment efficiency of DAF1 %	Treatment efficiency of SBR %	Treatment efficiency of DAF2 %	Total treatment efficiency %
BOD_5	75.29	**92.44**	69.23	99.50
COD	47.60	**82.48**	40.87	94.57
Color	59.19	**69.47**	69.40	96.19
NH_3–N	16.48	**99.33**	43.14	99.68
TSS	30.54	72.57	**75.13**	95.26
TDS	42.75	**61.21**	24.20	83.17
EC	43.83	**61.14**	24.31	83.48
Na	**51.63**	–8.87	–56.79	17.43
Ca	**34.35**	–11.21	–9.64	19.94
Mg	**48.96**	2.54	–69.79	15.54
Fe	32.67	**39.86**	2.65	60.58
Cu	**67.31**	64.71	50.00	94.23
Cd	**28.57**	20.00	–25.00	28.57
Pb	53.57	53.85	**100.00**	100.00
Mn	36.36	**61.90**	37.50	84.85
Ni	**32.43**	20.57	–18.71	36.29
Zn	15.63	**70.37**	37.50	84.38

study in which the values in bold are the highest removal efficiency achieved by the corresponding treatment as well as the total treatment efficiency.

Furthermore, CA was carried out to study the relationship between the 19 selected parameters to identify the similarity and dissimilarity between the behavior of selected parameters (Fig. 7), showing a dendrogram of the variables through various ponds. It can be seen that DO forms a cluster far from other parameters which indicated that DO behavior is entirely different from other ponds. The higher dissimilarity of DO is attributing to the higher change in the DO concentration during DAF and SBR treatment processes. During these processes, aeration is essential to enhance treatment performance.

4. Conclusion

With the aid of statistical techniques involving descriptive, factor analysis, and cluster analysis have actually imparted a better understanding and wide picture of the characteristics of the landfill leachate samples that were collected from four different stages of the landfill treatment facility in SUSL, raw leachate influent, primary, secondary, and tertiary effluents. Descriptive statistics helped to relate the findings to the corresponding regulations of the standard discharge limits for landfill leachate. On the other hand, factor analysis showed the possible sources of variations in the data can be represented by two factors explaining more than 95% of the total variation, 15.93% of variance due to Na, Ca, Mg, and Cd (factor 2) and 79.41% due to other parameters (factor 1). Furthermore, factor analysis showed that the four stages are entirely different based on the behavior of selected parameters. Similarities and dissimilarities among all the four different stages samples were identified using cluster analysis for a better classification of the studied parameters. According to the parameters in this research, the three treatments that were investigated in this study namely, DAF1, SBR, and DAF2 systems reported an effective reduction of the pollutants in the raw leachate sample.

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