



Assessment of Treatment Efficiency of Lysimeter Leachate using Leachate Pollution Index

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This study illustrates the leachate treatment efficiency based on leachate pollution index (LPI) of pre-treatment leachate as well as post-treatment leachate with chemical coagulants. Leachate samples were collected at regular intervals of time from the leachate collection chamber of the landfill lysimeter at KUET campus, Bangladesh to compute its pollution potential. The landfill lysimeter consists of one open dump lysimeter-A with leachate detection (A_1) and collection system (A_2) as well as two sanitary landfill lysimeters B and C having two different types of cap liner. The relevant parameters of leachate sample were measured in the laboratory to evaluate sub-pollution (sub-LPIs) in terms of LPI in organic pollutant (LPI_{or}), inorganic pollutant (LPI_{in}) and heavy metal (LPI_{hm}) as well as the overall LPI. Moreover, the values of LPI in pre-treatment leachate were to be found 19.53, 25.33, 23.48 and 23.74 for the A_1 and A_2 systems of open lysimeter-A, as well as the collection systems of sanitary lysimeters-B and C, respectively. It reveals significantly the higher values than that of LPI of 5.77, 7.38 and 7.38 for the maximum leachate discharge standards of Bangladesh, India and Hong Kong, respectively. The leachate was then treated with ferric chloride ($FeCl_3$), poly aluminum chloride (PAC), ferrus sulphate ($FeSO_4$) and aluminum sulphate ($Al_2(SO_4)_3$) in various dosages and pH values. The concentrations in post-treatment leachate by using $FeCl_3$ at optimum dosage were to be found below the limit of maximum leachate discharge standards. Study also reveals the values of LPI of 5.32, 5.69, 5.32 and 5.24 in post-treatment leachate for the A_1 and A_2 systems of open lysimeter-A, as well as the collection systems of sanitary lysimeters-B and C, respectively below the values of LPI in leachate of maximum discharge standards. Finally, it can be concluded that differences in the level of contaminants of pre-treatment and post-treatment leachate indicated the role of leachate treatment system in minimizing the level of contaminants and lowering the risk of leachate contamination based on LPI.

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INTRODUCTION

The best approach of the managing of municipal solid waste (MSW) generated from different sources are source reduction, reuse and recycling, but beyond this, the remaining MSW still have to be effectively managed using environmentally sound technologies [1, 2]. There are two commonly used options for the disposal of MSW; they are the open dumping and sanitary landfill [3]. In south and southeast Asia more than 90% of the MSW is disposed in an open dumping landfill [4]. The management of leachate is the most challenging factors to be considered in planning, designing, operating, and

long term managing of a MSW landfill [5]. Leachate can be contaminated the groundwater as well as surface water where the MSW landfills are not provided with liners and if it is not collected and treated prior to its discharged. The overall pollution potential of the MSW landfill leachate can be calculated in terms of the sub-pollution indices (sub-LPIs) as well as overall leachate pollution index (LPI) proposed by Kumar and Alappat [6]. The sub-LPIs and overall LPI can be used as a mean to determine whether a landfill requires immediate attention in terms of introducing remediation measures. The state regulatory authorities in almost of the countries have framed regulations to safe guard against

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the contamination of groundwater sources from the leachate generated from MSW landfills [7]. As the remedial and preventive measures are expensive, thus a system needs to develop, to classify the landfill in the basis of their hazard potential. Kumar and Alappat [8] have developed a technique to find the leachate contamination potential of the different landfills on a comparative scale in terms of LPI. LPI has many potential applications including the ranking of MSW landfill sites, resource allocation, trend analysis, enforcement of standards, scientific research and public information [9]. The formulation process and the complete description on the development of the LPI have been discussed elsewhere [10]. The present study is carried out to assess of landfill lysimeter leachate treatment efficiency by LPI. Then it was compared the derived LPI with the maximum discharge standards from different countries available in the literature.

The concentrations of landfill lysimeter leachate were measured in the laboratory through the required standard methods and most of the pollutant concentrations exceed the permissible limit of maximum discharge standards from some selected countries. Then it was required to treat for reducing the pollution concentrations before discharging into the natural streams [11], [12]. Moreover, the present study reveals the values of sub-LPI and overall LPI for the landfill lysimeter found significantly higher and proper treatment to be necessary before discharging the leachate into the natural water bodies. To meet the standard discharge condition, lysimeter leachate was treated through the chemical coagulation process by using ferric chloride (FeCl_3), poly aluminum chloride (PAC), ferrus sulphate (FeSO_4) and aluminum sulphate ($\text{Al}_2(\text{SO}_4)_3$) in various dosages and pH values. Result reveals that FeCl_3 more effective for removing the pollutant concentrations from lysimeter leachate. In the laboratory, leachate was further treated by using FeCl_3 at optimum dosage and the concentrations and consequently the values of LPI of treated leachate were to be found below the limit of maximum discharge standards.

MATERIAL AND METHODS

The landfill lysimeter site, leachate samples collection, chemical treatment, laboratory investigations as well as computing of LPI are described in the following sections.

Landfill Lysimeter Site

In this study, leachate samples were collected from the landfill lysimeter at KUET campus, Khulna, Bangladesh. In the study site, there are three lysimeters A, B and C to simulate the different landfill concept, operational condition and total weight of deposited MSW into each lysimeter is presented in Table 1. In open dump lysimeter-A, a compacted clay liner (CCL) of 400 mm thick as a base liner and a 150 mm thick of compost as a top cover were used to simulate the behaviour of present practice of open dumping in Bangladesh (Table 1). In lysimeter-A, the deposited MSW was not covered by a top cover system to prevent the movement of air, water and generated landfill gas (LFG). Moreover, the thickness of MSW in lysimeter-A was such that it was expected the atmospheric air can move into this cell with negligible inference. The lysimeter-A is treated as aerobic condition (open dump) comparing the other counterparts (sanitary landfill lysimeters-B and C). In contrast, in sanitary lysimeter-B, there was no base liner because this cell aimed to examine the applicability of the designed top cover (Table 1). In sanitary lysimeter-C, there was also no base liner and the provided top cover was different than that of the sanitary lysimeter-B (Table 1). In this case no CCL was provided; however, 900 mm thick natural top soil was used instead of 300 mm CCL and 600 mm thick top soil (Table 1). A leachate collection tank (3.68 x 1.56 x 1.64 m) was constructed using 250 mm thick brick wall accommodating four separate leachate discharge pipes in the temporary collection and storage containers.

Leachate Sampling and Laboratory Investigations

Leachate samples were sampled at regular intervals of time from the leachate collection chamber accomplished of four distinct collecting systems such as detection (A_1)

TABLE 1. Specifications and operational conditions of landfill lysimeter at KUET campus

Lysimeter	Operating condition	Refuse placed (kg)	Liner specification	Simulation
A	Open dump lysimeter with leachate detection (A_1) system	2860	400mm thick CCL as a barrier between detection and collection system of lysimeter-A	present practice of open dumping
	Open dump lysimeter with leachate collection (A_2) system			
B	Sanitary landfill lysimeter with gas measurement and leachate recirculation system	2985	Cap liner-I (300mm thick CCL)	applicability of designed top cover
C		2800	Cap liner-II (900mm thick natural top soil)	

and collection (A₂) system of the open dump lysimeter-A as well as the collection systems of the sanitary landfill lysimeters-B and C. In the laboratory, pH was determined by pH meter, chloride by potentiometric titration method using silver nitrate solution and total dissolved solid (TDS) dried at 103-105°C. BOD₅ by BOD meter, COD by closed reflux method, Total coliform bacteria (TCB) by filter membrane system as well as Arsenic using sulfamic acid and zinc powder were measured as per the standard method [13]. Ammonia nitrogen (NH₄-N) by nesslerization standard method and Total kjeldahl nitrogen (TKN) by macro-kjeldahl method as per the standard method [13] were determined in the laboratory. Moreover, Iron (Fe), Copper (Cu), Zinc (Zn), Chromium (Cr), Nickel (Ni) and Lead (Pb) were analysed using spectrophotometer (HACH; DR/2400) in accordance with the standard method [13]. All parameters were analyzed with three replications. Laboratory results were further subjected to statistical analyses, in order to facilitate interpretation. Using Microsoft Excel, the data was subjected to descriptive statistical analyses and the results are presented in Table 2. Correlations between pairs of metals were also obtained. In order to better understand the leachate parameter data from the concentration compared to different elapsed time. In addition, maximum, minimum, mean, variance, standard deviation, standard error, skewness and kurtosis were calculated for each parameter and also summarized in Table 2. The number of samples are also provided in Table 2. Unfortunately for COD concentration, limited samples and the standard deviation was high for the parameters, which means the trend of COD could be skewed. Further data would be needed to better understand the exact reason for the concentrations found in the leachate parameters.

Chemical Treatment of Leachate

The values of LPI in lysimeter leachate were determined using concentrations of parameters in leachate before treatment. Leachate treatment efficiency was evaluated based on LPI values in leachate before and after treatment by chemical coagulation process using FeCl₃, PAC, FeSO₄ and Al₂(SO₄)₃ in various dosages and pH values. At the initial stage, the optimum dosage of coagulants for the removal of pollutant concentrations was determined and this optimum dosage was further used for treating of leachate at varying pH between 4-9. Coagulation experiments were performed in a conventional Jar-test apparatus equipped with six backers. The experimental procedure consists of three subsequent stages; initial rapid mixing stage of 3 min at 110 rpm, following slow mixing stage of 25 min at 40 rpm and final settling for 30 min. The pH of leachate was adjusted to the desired levels by addition of the appropriate amounts of 6M sodium hydroxide or 6N sulfuric acid. After the settling time, the supernatant was withdrawn from the beaker and was

checked by chemical analysis. The withdrawal of sample was accomplished from a point about 2 cm below the liquid level in the beaker by a pipette.

Calculating of LPI Variable Selection

Eighteen leachate parameters were selected for inclusion in LPI [14]. They are pH, Total dissolved solids (TDS), Biochemical oxygen demand (BOD₅), Chemical oxygen demand (COD), Total kjeldahl nitrogen (TKN), Ammonia nitrogen (NH₄-N), Total iron (Fe), Copper (Cu), Nickel (Ni), Zinc (Zn), Lead (Pb), Chromium (Cr), Mercury (Hg), Arsenic (As), Phenolic compounds, Chlorides (Cl⁻), Cyanide (CN) and Total coliform bacteria (TCB).

Variable Weights

The weights for these eighteen parameters were calculated based on the significance levels of the individual pollutants. The weight factor indicates the importance of each pollutant variable to the overall leachate pollution. For example, the weight factor for Cr is 0.064, and so it is most important variable than the other pollutant variables, while Fe with a weight factor of 0.045 is least important variable as compared to other pollutant variables included in LPI [14] shown in Table 3. The weights for other pollutant variables are TDS: 0.050; BOD₅: 0.061; COD: 0.062; TKN: 0.053; NH₄-N: 0.051; Cu: 0.050; Ni: 0.052; Zn: 0.056; Pb: 0.063; Hg: 0.062; As: 0.061; Phenolic compounds: 0.057; Cl⁻: 0.049; CN: 0.058 and TCB: 0.052. The sum of the weights of all the eighteen parameters is one.

Variable Curves

The averaged sub index curves for each parameter were drawn to establish a relation between the leachate pollution and strength or concentration of the parameter. The sub-index curves for all the pollutant variables were reported by Kumar and Alappat [14]. The averaged sub index curves are the curves that represent the relation between leachate pollution and the strength or concentration of the parameters.

Variable Aggregation

In this study, the values of the three sub-pollution indices (sub-LPIs) in terms of LPI in organic pollutant (LPI_{or}), LPI in inorganic pollutant (LPI_{in}) and LPI in heavy metal (LPI_{hm}) as well as overall of LPI were evaluated. To derive the values of sub-LPIs as well as individual and overall pollutant rating of the landfill lysimeter, the detailed procedure advocated by Kumar and Alappat [14] was followed and hence discussed herein. After measuring pollutant concentrations in leachate, the sub-LPI was calculated using the following Equation 1. The overall LPI evaluated by using the aggregation of the

TABLE 2. Descriptive statistics of the characteristics of pre-treatment leachate in landfill lysimeter

Parameters	Sample size	Max				Min				Mean				Variance			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
pH	39	8.17	8.02	8.61	8.38	5.98	6.14	6.4	6.3	6.77	7.25	7.42	7.48	0.28	0.25	0.35	0.38
Cl-	39	3037	3572	1870	1810	970	1155	510	110	2237.8	2395.4	108.50	1181.2	244798	257565	85029	181366
TDS	39	9930	35810	29980	26000	210	140	1800	420	5391.4	12507.2	9786.3	13131.4	5814601	60909797	48000688	20768213
TCB	28	6540	8398	8200	8230	98	145	152	85	2826.5	3538.1	3432.6	3241.69	7786578	12295562	11918254	11039579
TKN	28	1120	1430	2187	1860	195	251	480	312	594.52	785.61	1307.0	1014.31	1070456	1778569	260047	321835
NH ₄ -N	28	705	901.3	997	965.7	187	127.9	190	187	428.5	547.6	653.3	598.3	3322	4233	48939	42901
BOD ₅	39	6750	22980	22670	22310	80	437	276	143	868.93	3775.0	3738.0	5043.83	2048650	35794836	48977719	57783698
COD	39	20800	60000	60000	60000	160	800	320	300	2498.1	8424.7	5654.0	11137.0	1377191	14194605	13834167	22730980
Zn	17	1.27	0.97	0.55	0.58	0.25	0.15	0.1	0.1	0.76	0.54	0.31	0.21	0.14	0.07	0.02	0.02
Cu	17	0.98	0.97	0.76	0.6	0.04	0.04	0.04	0.04	0.44	0.34	0.20	0.18	0.13	0.17	0.06	0.03
Cr	17	0.07	0.06	0.09	0.07	0.01	0.01	0.02	0.01	0.05	0.04	0.06	0.04	0.00	0.00	0.00	0.00
Pb	17	0.32	0.40	0.78	0.48	0.12	0.18	0.25	0.10	0.21	0.27	0.45	0.29	0.003	0.004	0.025	0.012
Ni	17	0.08	0.06	0.09	0.07	0.04	0.04	0.05	0.04	0.05	0.05	0.07	0.05	0.00	0.00	0.00	0.00
Fe	17	72.06	82.6	91.2	72	2.2	3.4	3.2	1.20	19.53	24.22	27.94	6.42	329.69	451.15	567.68	152.84
		<i>Standard deviation</i>				<i>Standard errors</i>				<i>Skewness</i>				<i>Kurtosis</i>			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
pH	39	0.53	0.49	0.59	0.62	0.05	0.08	0.09	0.09	1.19	-0.56	0.12	-0.29	1.03	-0.81	-0.65	-0.95
Cl-	39	494.77	507.51	291.60	425.87	79.23	81.27	46.69	68.19	-1.12	-1.01	0.31	-1.23	0.89	1.37	1.02	1.76
TDS	39	2411.35	7804.47	6928.25	4557.2	386	1249.	1109.4	729.74	0.25	1.56	1.96	0.16	-0.22	2.45	3.56	1.35
TCB	28	2790.44	3506.5	3452.28	3322.6	527.4	662.7	652.42	627.91	0.32	0.34	0.38	0.38	-1.83	-1.79	-1.77	-1.76
TKN	28	327.178	421.73	509.95	567.31	61.83	79.7	96.371	107.21	0.25	0.16	0.32	0.25	-1.79	-1.82	-1.05	-1.77
NH ₄ -N	28	182.3	205.7	221.2	207.1	34.45	38.88	41.81	39.14	0.28	-0.21	-0.54	-0.36	-1.36	0.04	0.23	-0.01
BOD ₅	39	1431.31	5982.88	6998.41	7601.5	229.2	958	1120.6	1217.2	3.55	2.55	2.17	1.51	12.77	5.65	3.14	0.55
COD	39	3711.05	11914.11	11761.8	15076.	594.2	1907.	1883.4	2414.2	3.60	3.01	3.49	1.67	15.44	9.47	12.77	1.79
Zn	17	0.38	0.27	0.16	0.13	0.09	0.06	0.04	0.03	-0.07	0.06	0.07	1.66	-1.73	-1.10	-1.39	2.73
Cu	17	0.36	0.41	0.25	0.18	0.08	0.09	0.06	0.04	0.47	0.77	1.59	1.36	-1.20	-1.56	0.99	0.57
Cr	17	0.02	0.01	0.02	0.02	0.01	0.00	0.01	0.01	-0.82	-0.38	-0.35	-0.34	-0.54	-0.41	-1.15	-1.31
Pb	17	0.055	0.060	0.158	0.108	0.013	0.014	0.037	0.026	-0.12	1.05	0.28	0.12	-0.17	0.45	-0.76	-0.77
Ni	17	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.31	0.26	0.15	0.57	-0.38	-1.37	-1.07	-1.33
Fe	17	18.157	21.24	23.83	12.363	2.908	3.401	3.815	1.980	1.74	1.35	1.22	4.55	2.45	0.86	0.54	22.11

Notation: Cl=chloride, TDS=total dissolve solid, TCB=total coliform bacteria, TKN=total kjeldahl nitrogen, NH₄-N=ammonia nitrogen, BOD₅= biological oxygen demand, COD=chemical oxygen demand, Zn=zinc, Cu=copper, Cr=chromium, Pb=lead, Ni=nickel and Fe=iron. All values in mg/L, except pH and TCB (cfu/100ml)

TABLE 3. Calculation of LPI in pre-treatment leachate at 7 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.076	0.21	0.17	0.09	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.41	0.55	0.92	0.65	7	7	9	8	0.441	0.441	0.567	0.504
COD	0.062	22650	60000	60000	56490	84	94	94	93	5.208	5.828	5.828	5.766
Mercury	-	-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	2080	2860	2790	2286	41	46	45	42	2.501	2.806	2.745	2.562
Arsenic	0.061	0.01	0.04	0.03	0.02	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide	-	-	-	-	-	-	-	-	-	-	-	-	-
Phenol	-	-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.4	1.5	0.98	0.65	5.5	5	5	5	0.308	0.28	0.28	0.28
pH	0.055	6.87	7.87	7.92	7.38	6	5	5	6	0.33	0.275	0.275	0.33
TKN	0.053	1010	2180	1430	1340	33	78	50	45	1.749	4.134	2.65	2.385
Nickel	0.052	0.1	0.19	0.13	0.12	5	5	5	5	0.26	0.26	0.26	0.26
TCB	0.052	6540	8280	8200	8230	85	89	90	90	4.42	4.628	4.68	4.68
NH ₄ -N	0.051	705	897	997	920	77	95	99	97	3.927	4.845	5.049	4.947
TDS	0.05	9876	35670	29120	26580	21	83	69	63	1.05	4.15	3.45	3.15
Copper	0.05	1.3	1.6	1.1	1.2	7	7	7	7	0.35	0.35	0.35	0.35
Chlorides	0.049	3037.00	3572.00	1350.00	760.00	23	31	12	8	1.127	1.519	0.588	0.392
Total Iron	0.045	25.9	45.7	43.5	38.7	5.5	6	6	6	0.2475	0.27	0.27	0.27
Summation	0.824									22.54	30.41	27.62	26.50
Derived LPI										27.36	36.91	33.52	32.16

Note: COD=chemical oxygen demand, BOD₅= biological oxygen demand, TKN=total kjeldahl nitrogen, NH₄-N=ammonia nitrogen, TCB= total coliform bacteria and TDS=total dissolve solid. All concentrations are in mg/L, except pH and total TCB (cfu/100ml) and NA= Leachate concentration not available.

three sub-LPIs. The three sub-LPI values were aggregated to calculate the overall LPI using following Equation (1).

$$LPI = (0.175LPI_{or} + 0.257LPI_{in} + 0.391LPI_{hm}) / 0.823 \quad (1)$$

Here, it can be noted that the Equation 1 was derived based on the weight factor of pollutants included in the overall LPI and their contribution to each sub-LPI. However, the components of organic, inorganic and heavy metal of 17.5, 25.7 and 39.10 % were used to derive the Equation 1, for evaluating the overall LPI.

In contrary, a study conducted by Kumar and Alappat [14] and found that for calculating overall LPI of waste disposal sites, the weighted sum linear aggregation function was the most suitable. The averaged sub-index curves for the selected eighteen (18) pollutant variables involving LPI have been reported by Kumar and Alappat [10] for evaluating sub index score of the leachate pollutant variables. Kumar and Alappat [14] also revealed that if the eighteen (18) leachate variables are known, Equation (2) can be used; otherwise, Equation (3) is to be used.

$$LPI = \sum_{i=1}^n w_i p_i \quad (2)$$

where, LPI = the weighted additive leachate pollution index, w_i = the weight for the i^{th} pollutant variable, p_i = the sub-index value of the i^{th} leachate pollutant variable, n = number of leachate pollutant parameters.

$$LPI = \frac{\sum_{i=1}^m w_i p_i}{\sum_{i=1}^m w_i} \quad (3)$$

$$\sum_{i=1}^m w_i < 1$$

where 'm' is the pollutant parameter for which data is available, in this research, $m < 18$ and

Procedure to Calculate LPI

The stepwise procedure to calculate LPI is given below.

Step 1 Testing of leachate pollutants

Analytical laboratory tests were performed to find out the concentration of the leachate pollutant variables on leachate sample collected from the landfill lysimeter site at regular intervals of time up to the elapsed time of 900 days.

Step 2 Calculating sub-index values

To calculate the LPI, one first computes the ' p_i ' values or sub-index values of parameter from the sub-index curves based on the concentration of the leachate pollutants obtained during the tests. The ' p_i ' values were obtained by locating the concentration of the leachate pollutant on

the horizontal axis of the sub index curve for that pollutant and noting the leachate pollution sub-index value where it intersects the curve.

Step 3 Aggregation of sub-index values

The ' p_i ' values obtained were multiplied with the respective weights (w_i) assigned to each parameter (Table 3). The sub-pollution indices in terms of LPI_{or} , LPI_{in} and LPI_{hm} were calculated using the corresponding weight factors based on the aggregation function. The overall LPI is evaluated by using the aggregation of the three sub-LPIs. The three sub-LPI values were aggregated to calculate the overall LPI using following Equation (1). In contrast, the Equation (2) is used to calculate LPI if the concentrations of all the eighteen variables included in LPI were known. Otherwise, Equation (3) was used when data for some of the pollutants is not available. It has been observed that LPI values can be calculated with marginal error using Equation (2), when the data for some of the pollutants is not available (Kumar and Alappat, 2004) [14]. In the present study, out of 18, 15 significant parameters were covered, so Equation (3) was used.

have been taken to mix for **biodiesel** production. The biodiesels were produced by different molar ratio of 4.5:1 and 6:1 with change in the amount of KOH catalyst as 1, 1.5 and 2 g for every sample. The stirring time was also changed for these samples from 30 to 60 minutes and the yields of biodiesel were observed.

Experimental Set Up & Alkali based Transesterification

Experiments were conducted in a 250ml glass vessel. Mixtures of karanja oil and linseed oil were taken and preheated to 110°C to remove any moisture content and then cool down to room temperature. Methanols were taken as per the molar ratio and mix with required amount of KOH catalyst and allow stirring at 50°C temperature till KOH dissolve completely. Now this methanol containing dissolved KOH mixed with 100ml mixed karanja and linseed oils and allow to stir for 30, 45 and 60 minutes at 60°C. After completion of reaction, it was cool and then allowed to settle down overnight. Next day, the upper layer of biodiesel was separated from lower layer of glycerol in a separating funnel. The biodiesel was water washed by hot water and then again, pure biodiesel were separated by physical separation method and the biodiesel was heated to 110°C to remove any moisture content. The biodiesel was weighed and the yields were estimated.

RESULTS AND DISCUSSION

The sub-pollution indices, overall LPI, comparison of LPI with other reseraches for similar cases, treatment

efficiency as well as LPI of post-treatment leachate were analyzed and the results are discussed in the following articles.

Sub-pollution Indices

The detection (A_1) and the collection (A_2) system of open dump lysimeter-A as well as collection systems of sanitary landfill lysimeters-B and C showed the higher component of organic fraction against the other counter fraction (inorganic and heavy metal fraction) in pre-treatment leachate. Consequently, the entire lysimeter operating systems showed the higher LPI_{or} than that of LPI_{in} and LPI_{hm} and shown in Figure 1. Result reveals comparatively the higher organic fraction in leachate for the A_2 system of open lysimeter-A and consequently the higher values of LPI_{or} than the other operating systems provided in Figure 2.

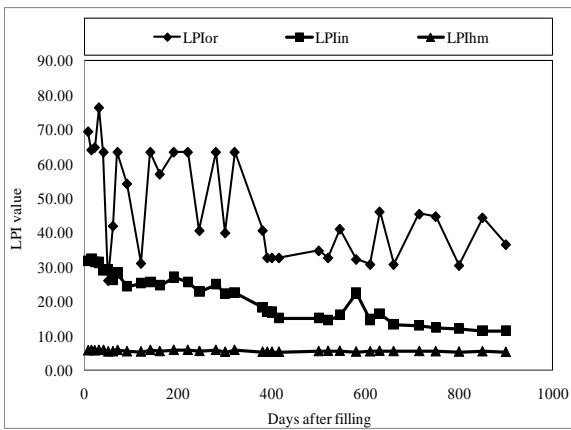


Figure 1. Sub-pollution indices in pre-treatment leachate of landfill lysimeter

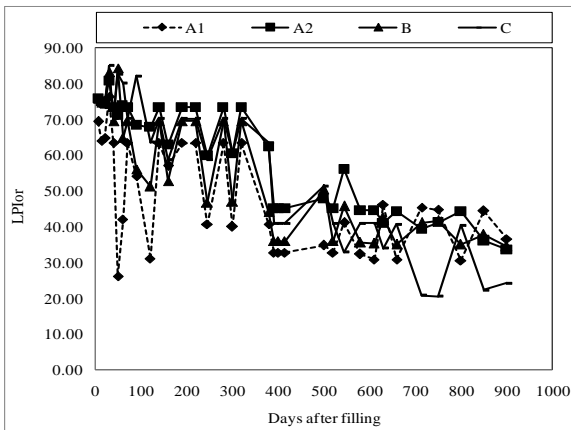


Figure 2. LPI_{or} in pre-treatment leachate of open and sanitary landfill lysimeters

Moreover, the values of LPI_{hm} were to be found comparatively lower due to the less concentrations of heavy metal in pre-treatment leachate for the entire lysimeter operating systems shown in Figure 3.

Moreover, due to the lower concentrations of inorganic compound in pre-treatment leachate for the A_1 system of open dump lysimeter-A against the other lysimeter operating systems, consequently showed the lower values of LPI_{in} shown in Figure 4. In contrary, comparatively the higher concentrations of inorganic compound in pre-treatment leachate than the concentration of heavy metal implies the higher LPI_{in} than that of LPI_{hm} . In addition, the higher inorganic compound in pre-treatment leachate implies the higher values of LPI_{in} for the A_2 system of open lysimeter-A (Figure 4). It can be noted that the component of organic fraction in pre-treatment leachate was to be found higher for the entire lysimeter operating systems against the other counter fraction (inorganic and heavy metal fraction) and consequently showed the higher LPI_{or} than that of LPI_{in} and LPI_{hm} . Result shows the higher sub-LPIs for the collection (A_2) system of open lysimeter-A than that of other lysimeter operating systems.

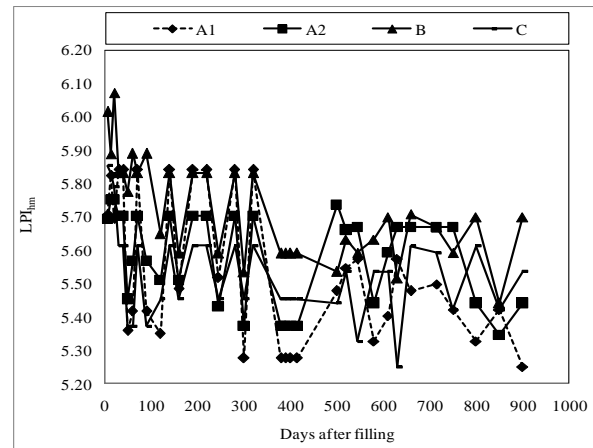


Figure 3. LPI_{hm} in pre-treatment leachate of open and sanitary landfill lysimeters

Overall Leachate Pollution Index

The values of LPI in pre-treatment leachate were derived in relation to the variation of lysimeter operating systems such as detection (A_1) and collection (A_2) system of open dump lysimeter-A as well as the collection systems of the sanitary landfill lysimeters-B and C, at the elapsed period ranging from 7-900 days after filling of MSW in the landfill lysimeter. At the elapsed time of 7 days, the A_2 system of open lysimeter-A depicted the higher values of LPI (36.91) in pre-treatment leachate than that of the other lysimeter operating systems provided in Table 3 and Figure 5. The highest value of LPI in pre-treatment leachate for the A_2 system of open lysimeter-A further indicated that the deposited MSW in lysimeter-A has not yet stabilized. This was also evident from the higher values of BOD_5 and COD. Figure 5 depicted that the A_2 system of open lysimeter-A had the highest LPI, while, the lowest for the A_1 system of lysimeter-A until the

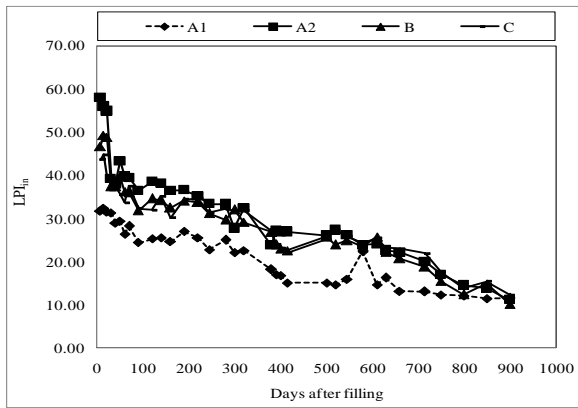


Figure 4. LPI_{in} in pre-treatment leachate of open dump and sanitary landfill lysimeter

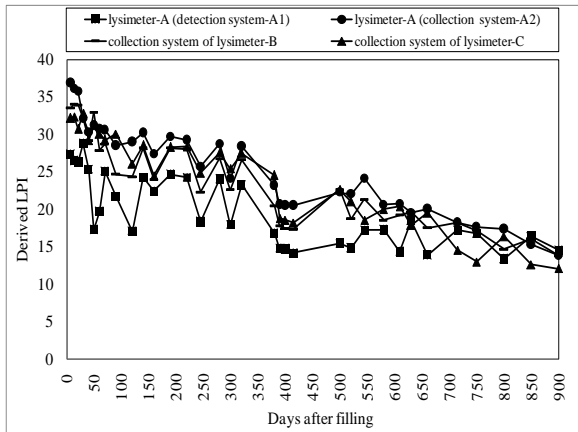


Figure 5. Variation of LPI in pre-treatment leachate with period of lysimeter at varying operational condition

completion of this study. Result reveals the concentrations of Cr, BOD₅, As, Zn, TKN, Ni, TCB, TDS, Cu, Cl⁻ and Fe in pre-treatment leachate were to be found higher for the A₂ system of lysimeter-A, while the collection system of the sanitary lysimeter-B contained comparatively the higher concentrations of Pb, pH and NH₄-N (Table 3). A significant difference between the individual and overall pollution ratings for both the collection systems of the open lysimeter-A and the sanitary landfill lysimeter-B was observed due to the distinct difference of their leachate concentrations before treatment.

Moreover, the pollutant concentrations of As, Ni, NH₄-N and Cu in pre-treatment leachate were to be found fairly similar for both the collection systems of the sanitary lysimeters-B and C. Although these two landfill lysimeter exhibited notable differences for the concentrations of Cr, BOD₅, Zn, TDS, Cl⁻ and Fe in leachate, but the influence of the individual and cumulative polluting rating was insignificant. So, it can be concluded that these distinct variation of leachate concentrations before treatment, finally implies the

varied individual, cumulative pollutant rating and the overall LPI.

Comparison of LPI in Pre-treatment Leachate with Published Results

The comparison of the mean values of derived LPI in pre-treatment leachate at the distinct operational conditions of the landfill lysimeter with the published results available in the literature for the same cases is provided in Figure 6. In this study, the derived mean values of LPI in pre-treatment leachate were to be found 19.53, 25.33, 23.48 and 23.74 for the A₁ and A₂ systems of open dump lysimeter-A, as well as the collection systems of sanitary lysimeters-B and C, respectively. The results obtained by this study indicted clearly that the pollution potential of leachate in landfill lysimeter site is high and number of variables included in LPI measure should be considered in comparison to the results for other landfill sites in other places.

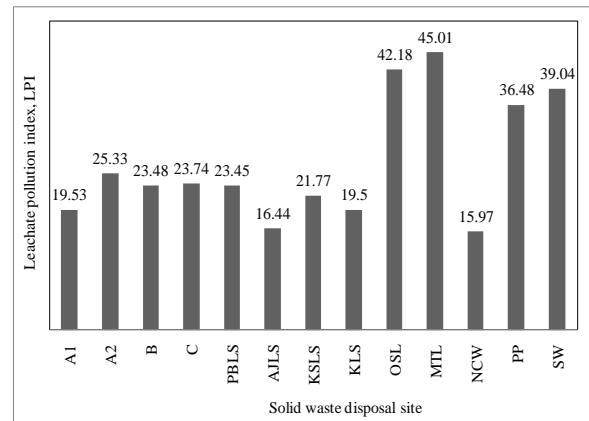


Figure 6. Comparison of contamination potential of pre-treatment leachate of lysimeter with other researchers

A study conducted by Umar et al. [7] for calculating of LPI and selected four solid waste disposal sites in Malaysia, namely, Pulau Burung landfills (PBLS) (sanitary landfill level III through leachate recirculation and controlled tipping), Ampang Jajar Landfill Site (AJLS) (semiaerobic closed landfill having no base liner), Kuala Sepetang Landfill Site (KSLS) (improved anaerobic landfill, natural marine clay and local soil are used as cover material for dumped waste with leachate collection pond) and Kulim Landfill Site (KLS). The values of LPI were found as 23.45, 16.44, 21.77 and 19.50 for PBLS, AJLS, KSLS and KLS disposal sites, respectively.

On the other hand, Kumar and Alappat [8], [14] were selected Okhla sanitary landfill (OSL), New Delhi (no base liner or leachate collection and treatment systems) solid waste disposal site as a case study for calculating of LPI and it was found 42.18. A study conducted by Kumar and Alappat [6] and selected four landfill, namely, Ma

Tso Lung (MTL) and Nagu Chi Wan (NCW) closed landfill sites as well as Pillar Point (PP) and Shuen Wan (SW) active landfill sites in Hong Kong for the calculating of LPI and it was found as 45.01, 15.97, 36.48 and 39.04, respectively. Here, it can be concluded that among the selected disposal sites, four landfill of OSL, MLT, PP and SW having more LPI due to their operational configuration than that of LPI in leachate before treatment of present landfill lysimeter studies because it was a pilot scale landfill experiment.

It can be noted that laboratory result reveals the pollutant concentrations in pre-treatment leachate exceeded the permissible limit of maximum discharge standard provided in Table 4. Moreover, the values of the sub-LPIs and overall LPI in pre-treatment leachate for the landfill lysimeter were to be found significantly higher and the proper treatment to be necessary before the discharging of leachate into the natural water bodies.

Results of Leachate Treatment at Optimum Condition

The optimum results were achieved after treating of leachate for removing of pollutant using different coagulants of FeCl_3 , PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ at optimum coagulation dose of 3000, 4000, 3000 and 2000 mg/L, respectively, at optimum value of pH 7 and the mixing speed of 110 rpm provided in Table 5. The used four chemical coagulants showed the varying percentages of reduction in concentration of pollutants in post-treatment leachate at optimum coagulant dosage with varying pH. The chemical coagulant of FeCl_3 was able to achieve the complete removal (100 %) of the concentrations of Ca, K, Na, Cu, Cd, Ni and Pb at optimum coagulant dosage, while at optimum pH it was able to achieve the complete removal of Cd, Ni and Pb in leachate (Table 5). Result shows that the optimum reduction of turbidity was to be found 95, 89 and 93 % as well as 93, 85 and 82 % for Zn, by using FeCl_3 , PAC and FeSO_4 at optimum coagulant dosage, respectively. Here, it can be concluded that FeCl_3 was found more effective for the removal of all the pollutant concentrations in leachate at optimum pH than the other chemical coagulants. To reduce the pollutant concentrations in leachate by using FeCl_3 at optimum condition, the leachate samples were also collected from the four distinct operational conditions such as detection (A_1), collection (A_2) system of open dump lysimeter-A, collection systems of sanitary lysimeters-B and C were tested in the laboratory and the concentrations of treated leachate are shown in Table 7.

Comparison of LPI in Post-treatment Leachate with Maximum Discharge Standards

In an effort to assess the pollution potential of leachate and to assess whether the leachate treatment system is

efficient, LPI in pre-treatment leachate (Table 3) and post-treatment leachate (Table 6) were computed. It is a quantitative and comparative measure for the leachate pollution potential and by which the leachate pollution data of the landfill sites can be reported uniformly [6], [15]. It was found that the high values of LPI value in pre-treatment leachate were remarkably reduced after treatment. This leads to minimizing the levels of pollutants and the risk of pollution.

The permissible limit for the disposal of leachate into the natural water bodies and their corresponding LPI as per the standard set by DoE (Bangladesh) on ECR, 97 for Effluent (Wastewater) reported by [16], the management and handling rule by the Gazette of Government of India [17] as well as in Hong Kong stated by Environmental Protection Department [18] are provided in Table 6. Result reveals that the pollutant concentrations in pre-treatment leachate of the landfill lysimeter-A, B and C were exceed the permissible limit of leachate discharge standards. The comparison of the characteristics pre-treatment leachate of the landfill lysimeter with the standard set for the disposal of treated leachate verified the fact that the leachate generated from the landfill lysimeter was highly contaminated and will have to be treated before discharging into the natural streams. Moreover, the values of LPI were to be found 19.53, 25.33, 23.48 and 23.74 in the pre-treatment leachate for the A_1 and A_2 systems of open lysimeter-A, as well as the collection systems of sanitary lysimeters-B and C, respectively indicated that the landfill lysimeter is contaminated. It reveals significantly the higher values than that of LPI of 5.77, 7.38 and 7.38 for the maximum leachate discharge standards of Bangladesh, India and Hong Kong, respectively. For reducing of pollutant concentrations in leachate by using FeCl_3 at optimum condition, the leachate samples were sampled from the four distinct operational conditions such as detection (A_1), collection (A_2) system of open dump lysimeter-A, collection systems of sanitary lysimeters-B and C then tested in the laboratory shown in Table 6. The concentrations and consequently the values of LPI in post-treatment leachate were to be found below the limit of maximum discharge standards indicated the efficiency of leachate treatment minimizing leachate pollutants. Study reveals the LPI values below the maximum discharge standards of 5.32, 5.69, 5.32 and 5.24 in post-treatment leachate for the A_1 and A_2 systems of open lysimeter-A, as well as the collection systems of sanitary lysimeters-B and C, respectively. Comparison of LPI in pre-treatment and post-treatment leachate with leachate discharging standards is shown in Figure 7. It can be concluded that the leachate generated from the landfill lysimeter may be discharged into the natural streams after the required level of chemical treatment to maintain the limit of maximum discharge standards.

TABLE 4. Comparison of concentration in post-treatment leachate and maximum discharge standard

Parameter	Standard set by DoE (Bangladesh) ⁽¹⁾				India ⁽²⁾	Hong Kong ⁽³⁾	Standard A ⁽⁴⁾	Standard B ⁽⁴⁾	Concentration of post-treatment leachate of lysimeter			
	Inland Surface Water	Public Sewerage System Connected to treatment at Second Stage	Irrigated Land						A ₁	A ₂	B	C
Cr	0.5	1	1	2.0	0.1	0.2	1.0	0.045	0.04	0.08	0.07	
Pb	0.1	1	0.1	0.1	0.1	0.01	0.5	0	0	0	0	
COD	200	400	400	250	200	50	100	55	85	60	57	
Hg	0.01	0.01	0.01	0.01	0.02	0.005	0.05					
BOD ₅	50	250	100	30	800	20	50	85	102	88	80	
As	0.2	0.05	0.2	0.2	-	0.05	0.1	0.01	0.04	0.03	0.02	
CN	0.1	2	0.2	0.2	-	0.05	0.1	-	-	-	-	
Phenol	1	5	1	1.0	-	0.001	1.0	-	-	-	-	
Zinc	5	10	10	5.0	0.6	1.0	1.0	1.13	0.92	0.55	0.576	
pH	6-9	6-9	6-9	5.5-9.0	5-7.5	6.0-9.0	5.5-9.0	6.1	6.27	6.45	6.21	
TKN	100	100	100	100	100	-	-	95	180	112	51	
Ni	1	2	1	3.0	0.6	0.2	1.0	0	0	0	0	
NH ₄ -N	50	75	75	50	5.0	-	-	-	-	-	-	
TCB	-	-	-	-	-	-	-	27	45	25	33	
TDS	2100	2100	2100	2100	500	-	-	980	1100	1002	780	
Cu	0.5	3	3	3.0	1.0	0.2	1.0	0.04	0.04	0.04	0.04	
Cl ⁻	600	600	600	1000	850	1.0	2.0	540	900	602	511	
Fe	2	2	2	-	-	-	-	5.1	3.2	3.3	2.1	

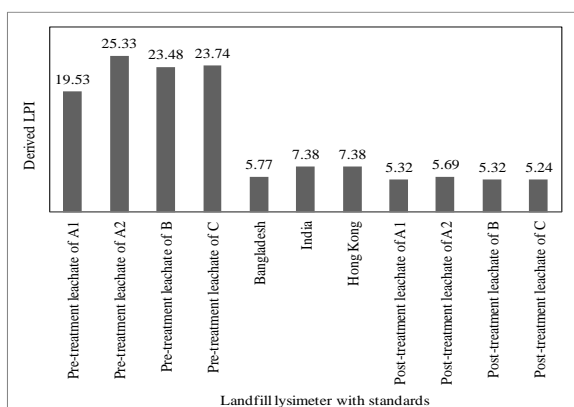
Notation: ¹Jannatul F 2013 (Standards Set by DoE on ECR, 97 for Effluent (Wastewater, inland surface water); ²Kumar and Alappat 2003a; ³Environmental Protection Department (EPD) (Maximum discharge standard for landfill leachate from selected countries) and ⁴Standard A: Upstream of water supply intake and ⁴Standard B: Downstream of water supply intake (Regulatory Standards for industrial wastewater as specified in the Environmental Quality (Sewage and Industrial Effluents) Regulation, 1979; EQA, 1974).

TABLE 5. Comparative reduction of pollutant in treated leachate using coagulant at optimum condition

Coagulant	Optimum Condition	Removal efficiency (%)														
		Turbidity	Color	COD	TSS	BOD ₅	NH ₄ -N	Calcium	Potassium	Sodium	Manganese	Copper	Zinc	Cadmium	Nickel	Lead
FeCl ₃	3000mg/L	95	86	50	81	41	75	100	100	100	80	100	93	100	100	100
	pH 7	94	88	50	79	39	67	96	86	86	86	81	83	100	100	100
PAC	4000mg/L	89	86	41	79	39	69	93	83	82	86	77	85	72	78	53
	pH 7	91	88	45	80	38	64	94	84	84	91	85	82	93	86	96
FeSO ₄	3000mg/L	93	87	32	79	38	67	92	83	82	83	83	82	74	60	96
	pH 7	92	95	37	79	36	62	95	88	88	95	82	82	93	84	95
Al ₂ (SO ₄) ₃	2000mg/L	92	88	40	79	37	66	94	85	84	89	84	83	77	57	74
	pH 7	90	89	41	81	35	63	95	85	85	92	86	85	93	86	94

TABLE 6. Comparison of LPI in post-treatment leachate of landfill lysimeter and maximum discharge standards

Serial No.	Leachate pollutant	Leachate discharge standard			Concentration in post-treatment leachate of landfill lysimeter			
		Bangladesh	India	Hong Kong	A ₁	A ₂	B	C
1	Chromium	0.5	2	0.1	0.045	0.04	0.08	0.07
2	Lead	0.1	0.1	0.1	0	0	0	0
3	COD	200	250	200	55	85	60	57
4	Mercury	0.01	0.01	0.02	-	-	-	-
5	BOD ₅	50	30	800	85	102	88	80
6	Arsenic	0.2	0.2	-	0.01	0.04	0.03	0.02
7	Cyanide	0.1	0.2	-	-	-	-	-
8	Phenol	1	1	-	-	-	-	-
9	Zinc	5	5	0.6	1.126	0.92	0.55	0.576
10	pH	6-9	5.5-9.0	5-7.5	6.1	6.27	6.45	6.21
11	TKN	100	100	100	95	180	112	51
12	Nickel	1	3	0.6	0	0	0	0
13	TCB	-	-	-	-	-	-	-
14	NH ₄ -N	50	50	5	27	45	25	33
15	TDS	2100	2100	500	980	1100	1002	780
16	Copper	0.5	3	1	0.04	0.04	0.04	0.04
17	Chlorides	600	1000	850	540	900	602	511
18	Total Iron	2	-	-	5.1	3.2	3.3	2.1
	Corresponding LPI	5.77	7.38	7.38	5.32	5.69	5.32	5.24

**Figure 7.** Comparison of LPI in pre-treatment and post-treatment leachate with leachate discharging standards

CONCLUSION

High value of LPI of landfill lysimeter site indicated that leachate generated is contaminated. The landfill lysimeter sites requiring immediate attention can also be prioritized based on LPI to avoid incidents of immense pollution because changes in individual quality parameters alter the value of LPI. Leachate treatment efficiency was evaluated based on LPI values in pre-treatment leachate as well as post-treatment leachate using chemical coagulants. Through this study it was found that the values of LPI were to be 19.53, 25.33, 23.48 and 23.74 in pre-treatment leachate as well as 5.32, 5.69, 5.32 and 5.24 in post-treatment leachate for the A₁ and A₂ systems of open lysimeter-A, as well as the collection systems of sanitary lysimeters-B and C, respectively. The operation of leachate treatment system in terms of chemical dosing and leachate collection

should be controlled and more attention should be given to the landfill management. In addition, the values of LPI in post-treatment leachate were to be found below the permissible limits. The overall conclusion in this study would be that the differences in the level of contaminants in leachate before and after treatment indicated the role of leachate treatment system in minimizing the level of contaminants and lowering the risk of leachate contamination.

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Persian Abstract

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چکیده

در این پژوهش بازده تیمار شیرابه بر اساس شاخص آلودگی شیرابه (LPI) برای شیرابه پیش تیمار شده و پس تیمار شده با لخته سازهای شیمیایی مورد بررسی قرار گرفت. نمونه های شیرابه در فواصل منظم زمانی از محفظه جمع-آوری شیرابه یک لایسیتر محل دفن زباله در KUET بنگلادش برداشته شد تا پتانسیل آلودگی آن محاسبه شود. لایسیتر مستقر در محل دفن زباله از یک لایسیتر باز-A که شامل یک آشکارگر شیرابه (A1) و یک سیستم جمع-آوری (A2) است تشکیل شده است که همانند لایسیتر بهداشتی B و C دو نوع مختلف آستر کلاهی (cap liner) دارند. پارامترهای مربوط به نمونه های شیرابه در آزمایشگاه اندازه گیری شد تا آلودگی های آن در غالب LPI برای آلاینده های آلی، آلاینده های غیر آلی، فلزات سنگین و LPL کل ارزیابی شود. علاوه بر این مقدار LPI در شیرابه پیش تیمار برای سیستم A1 و A2 لایسیتر باز-A و لایسیترهای بهداشتی B و C به ترتیب 19/53، 25/33، 23/48 و 23/74 بوده است. این مقادیر بسیار بیشتر از ماکزیمم بار شیرابه استاندارد در کشورهای بنگلادش، هند و هنگ کنگ که به ترتیب 5/77، 7/38 و 7/38 است، می باشد. سپس شیرابه با استفاده از آهن کلرید ($FeCl_3$)، پلی آلومینیوم کلرید (PAC)، آهن سولفات ($FeSO_4$) و آلومینیوم سولفات ($Al_2(SO_4)_3$) در غلظت ها و مقادیر pH مختلف تیمار شد. غلظت شیرابه در شیرابه پس تیمار شده با آهن کلرید ($FeCl_3$) در غلظت اپتیمم پایین تر از حد ماکزیمم بار استاندارد بود. این مطالعه نشان داد که مقادیر LPI در شیرابه پس تیمار برای سیستم های A1، A2 لایسیتر باز A و سیستم های لایسیتر بهداشتی B و C به ترتیب 5/32، 5/5 و 5/24 می باشد که پایین تر از حد ماکزیمم بار استاندارد LPI می باشد. نهایتاً می توان اینطور نتیجه گرفت که تفاوت در سطح آلودگی در شیرابه پیش تیمار و پس تیمار نشان دهنده نقش سیستم تیمار شیرابه در کاهش سطح آلودگی ها و پایین آوردن ریسک آلودگی شیرابه بر پایه LPI می باشد.