

Modelling Leachate Pollution Index and Potential for Selected Municipal Solid Waste Dump Sites in Warri Metropolis, Nigeria

ABSTRACT

Unengineered and uncontrolled dump sites is a threat to human and the environment. Leachate infiltration from Municipal Solid Waste (MSW) posed great threats to surface and groundwater systems. Leachate samples were collected from Niger-Cat (NC), Don-Parkar (DP) and Orhuwhorun (ORH) dump sites for September, November and January by Random Sampling (RS) technique and concentration of selected leachate parameters were determined. Principal Component Regression (PCR) analysis was employed to model Leachate Pollution Index (LPI) and pollution potentials of leachate of NC, DP and ORH dump sites to ascertain the threats posed to surface and groundwater systems of the immediate environment of the dump sites. The modelled LPI values at NC were 16.492, 16.162 and 14.599, at DP modelled LPI values were 15.714, 15.119 and 18.883 while at ORH modelled LPI values were 12.379, 11.940 and 12.072 for September, November and January respectively. The LPI values were compared with the LPI standard value (7.378) for the disposal of leachate. It was revealed that the LPI values were above the maximum permissible limit, which indicated that the leachate generated from these dump sites are of high pollution potentials. It therefore implied that NC, DP and ORH are sources of contamination and the local surface and groundwater systems are at risk. Thus, with passage of time, there is a possibility of groundwater contamination even to a greater margin if no measure is put in place to check these threats.

Keyword: Leachate Pollution Index, Principal Component Regression, Model, Pollution Potential, Dump Site, Groundwater

1. INTRODUCTION

Inappropriate management of municipal solid waste continues to be a major problem facing the world [1]. Municipal solid waste (MSW) consists of wastes generated from households and commercial places as it relates to daily human activities. Unscientific dumping and the burning of municipal solid wastes result in serious environmental issues such as; land pollution, surface water pollution, groundwater pollution, and air pollution [2,3,4,5]. Landfilling is the most commonly used method for the management of municipal solid waste [6,7].

Low and middle income nations are still heavily dependent on landfill as a means of waste disposal, because it remains one of the simplest, cheapest and the most commonly used method for disposal of municipal solid wastes [8]. This method of municipal waste disposal in many countries is characterized with severe negative impacts on the environment [9].

Typically, little attention has been given to proper siting and engineering of landfill to avert the hazards of the generation of methane and toxic leachates as wastes decompose [10].

In most developing nations like Nigeria, a greater amount of municipal solid wastes generated ends up in the open dumps [11]. Warri is characterized by shallow groundwater [12], which makes it vulnerable to contamination from leachate of high pollution potential from non-sanitary landfills (dump sites). Surrounding soil, nearby surface water and groundwater contamination from municipal solid waste landfill leachate had been widely reported in literature [13-21]. The objective of this study is to develop models for predicting and monitoring leachate pollution index and potentials of Niger-Cat, Don-Parkar and Orhuwhorun dump sites and threat posed to local groundwater system.

2. METHODOLOGY

2.1 STUDY AREA

Warri is located within the Niger Delta in the southern part of Nigeria. It lies within Latitude $5^{\circ}32'N$ to $5^{\circ}40'N$ and Longitude $5^{\circ}42'E$ to $5^{\circ}50'E$, covering an area of about 499.81km^2 . The population is estimated at 663,000 [22]. The climate of Warri is equatorial which is marked by two distinct seasons. The dry season that stretches from November to April, and wet season that spans May to October with maximum mean temperature reaching up to 37°C and minimum mean temperature at about 23°C with relative humidity of 50 - 70 percent. The mean annual rainfall is 2673.8mm [23]. The natural vegetation is of rainforest with swamp forest in some areas. The study area is with respect to three dump site locations. (1) The Niger-Cat waste dump site, which lies within $5^{\circ}34'31.72''N$ and $5^{\circ}44'53.41''E$ along the NPA Expressway, Ekpan, Uvwie LGA of Warri metropolis, (2) the Don-Parkar dump site, which lies within latitude $5^{\circ}40'50.24''N$ and longitude $5^{\circ}45'17.61''E$ along Warri-Sapele Expressway, Okuovo, Okpe LGA and (3) the Orhuwhorun dump site located within latitude $5^{\circ}30'59.40''N$ and longitude $5^{\circ}50'52.38''E$ along Warri-Ajaokuta Rail line, Orhuwhorun, Ughelli South LGA [24].



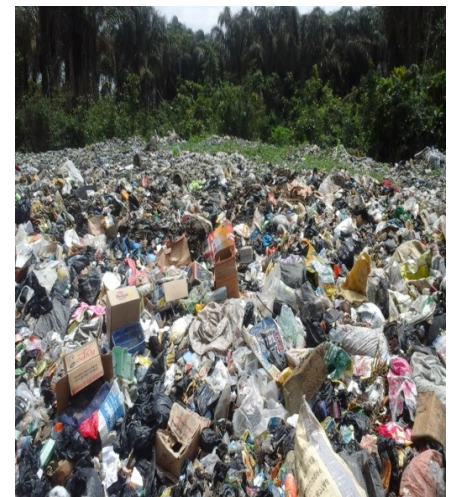
Figure 1: Map of Warri metropolis where the study was carried out



(a) Niger-Cat



(b) Don-Parkar



(c) Orhuwhorun

Figure 2: Sectional view of the three dump sites

2.2 DATA COLLECTION

Random sampling technique was employed. Three leachate samples were randomly collected from three different locations of the dump sites. Leachates were scooped from the base of the heap of waste where leachate had drained out by gravity. Samples were collected in 1-litre polyethylene bottles which were properly cleaned with detergent and rinsed with clean water and allowed to dry prior to sampling. Sampling was conducted for the month of September and November, 2015 and January, 2016. Sampling points were geo-referenced using GPS device “Garmin GPSmap76CSx”. Unstable parameters (such as pH and Total Dissolved

79 Solids) were determined in-situ, and samples were cooled to 4⁰C in ice container. These
 80 conditions were maintained until the samples were received at the laboratory. Analysis of
 81 leachate samples was according to the American Public Health Association [25] standards for
 82 examining water and wastewater. Samples were analyzed for various physico-chemicals and
 83 biological parameters viz. pH, Total Dissolved Solids, Biological Oxygen Demand, Chemical
 84 Oxygen Demand, Ammonia, Phenol, Nickel, Chromium, Iron, Lead, Copper, Zinc and Total
 85 Coliform bacteria.

86 **2.3 DATA ANALYSIS**

87
 88 The method employed in the analysis of generated raw data for the determination of pollution
 89 potential was the Weighted Additive Leachate Pollution Index (WALPI) as proposed by
 90 Kumar [14] and Principal Component Regression (PCR). PCR was adopted to formulate
 91 models for the estimation of Leachate Pollution Index with respect to dump sites of the study
 92 area.

93 **2.3.1 Leachate Pollution Index (LPI)**

94 Leachate Pollution Index (LPI) is a tool for assessing pollution potential of leachate from
 95 municipal solid waste dump sites. The objective of LPI is to present complex leachate data
 96 into information that is understandable and usable by the public. It is an environmental index
 97 used to quantify the leachate contamination potential of municipal solid waste dump sites.
 98 This index is based on the concentration of eighteen (18) parameters of the leachate and their
 99 corresponding significance. In order to calculate the LPI of a landfill, concentration of these
 100 18 parameters are to be known.

101 With regards to this study, the sub-index values for all the parameters analyzed were
 102 computed from the sub-index curves based on their concentration. The sub-index values
 103 obtained for the parameters analyzed were multiplied with the respective weights assigned to
 104 each parameter. The Weighted Additive Leachate Pollution Index method is computed using
 105 Equation (1) when concentrations of all eighteen (18) parameters are known.

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

106 where, LPI = the weighted additive leachate pollution index, w_i = the weight for the
 107 i^{th} pollutant variable, p_i = the sub index value of the i th leachate parameter, $n = 18$ and $\sum w_i = 1$.

108 However, when the data for the eighteen (18) variables for computing LPI are not known, the
109 LPI can be calculated using Equation (2) as given [14].

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

110 m is number of pollutant parameters for which data is available, but in that case, $m < 18$ and
111 $\sum w_i < 1$.

112 2.3.2 Principal Component Regression (PCR)

113 Principal component regression is a regression technique that is based on Principal
114 Component Analysis (PCA). It considers regressing the outcome (the dependent variable) on
115 a set of covariates (the independent variables) based on a standard linear regression model.
116 Principal Component Regression involves two steps:

117 i. Application of PCA to decompose the independent variables(x) into an orthogonal
118 basis (i.e. principal components or factor components), and select a subset of those
119 components as the variables to predict the dependent variable(y). Principal component
120 analysis looks for a few linear combinations of the variables that can be used to
121 summarize the data without losing too much information in the process. Equation (3)
122 presents the basic equation for principal component [26]:

$$123 \quad z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \dots + a_{im}x_{mj} \quad (3)$$

124 where z is the component score, a is the component loading, x the measured value of variable,
125 i is the component number, j the sample number and m the total number of variables.

126 ii. Construction of linear regression between the parameters on the factors most
127 correlated with y .

$$128 \quad Y = \sum_{i=0}^{j \leq k} \gamma_i \text{Factor}_i + \beta \quad (4a)$$

$$129 \quad \text{where } \text{Factor}_i = \sum_{l=0}^k a_l x_l$$

130 So

$$131 \quad Y = \sum_{i=0}^K a_i x_i + \beta$$

132 (4b)

133 where Y is the dependent variable, x_i is the independent variables, a_i is the regression
134 coefficients and β is the error or residual.

2.3.3 Modelling of Leachate Pollution Index

In order to develop the models, a statistical tool called “XLSTAT” 2016 (Version 6) statistical package was employed. Firstly, the thirteen (13) independent parameters (pH, TDS, BOD, etc.) were subjected to Principal Component Analysis (PCA) to identify the most meaningful parameters (Principal Components or Factors) that give information that describe the majority of the data set, thereby allowing for data reduction with minimum loss of original information [27] and secondly, multiple linear regression between the dependent variable (the observed LPI values) from the results of Equation (2) and the independent variables (Principal Components or Factors) was carried out.

Table 1: Input Data for Model Development for Niger-Cat Dump Site

Parameter [±]	September	November	January
pH	6.97	7.89	6.69
TDS	2827.33	2066.00	3100.00
BOD	397.10	444.03	327.43
COD	1020.33	916.67	737.33
NH ₃ -N	54.90	59.54	31.22
Nickel (Ni)	0.15	0.14	0.17
Chromium (Cr)	0.57	0.49	0.23
Total iron (Fe)	6.43	3.94	9.71
Lead (Pb)	0.96	0.98	0.11
Copper (Cu)	0.19	0.17	0.21
Zinc (Zn)	7.06	6.98	4.28
Phenol	0.01	0.01	0.01
Total coliform (TC)	16000.00	16000.00	16000.00
LPI	16.636	15.989	14.528

[±] All parameters are in mg/l except pH and total coliform (MPN/100ml)

Table 2: Input Data for Model Development for Don-Parkar Dump Site

Parameter [±]	September	November	January
pH	6.37	7.15	8.01
TDS	3373.33	3290.00	5426.67
BOD	358.47	309.47	545.60
COD	816.00	707.00	1242.67
NH ₃ -N	74.41	60.58	76.12
Nickel (Ni)	0.13	0.10	0.26
Chromium (Cr)	0.53	0.23	0.58
Total iron (Fe)	9.03	7.90	19.68
Lead (Pb)	0.88	0.62	0.96
Copper (Cu)	0.17	0.10	0.52
Zinc (Zn)	5.77	3.31	11.97
Phenol	0.01	0.01	0.01
Total coliform (TC)	16000.00	16000.00	16000.00
LPI	15.845	15.008	18.862

[±] All parameters are in mg/l except pH and total coliform (MPN/100ml)

Table 3: Input Data for Model Development for Orhuwhorun Dump Site

Parameter [±]	September	November	January
pH	6.90	6.44	7.22
TDS	950.00	780.00	1153.33
BOD	69.17	63.17	70.07
COD	92.83	76.33	85.13
NH ₃ -N	33.09	18.28	43.03
Nickel (Ni)	0.11	0.06	0.17
Chromium (Cr)	0.44	0.16	0.31
Total iron (Fe)	1.68	1.20	2.19
Lead (Pb)	0.82	0.45	0.16
Copper (Cu)	0.15	0.06	0.18
Zinc (Zn)	1.79	2.32	2.79
Phenol	0.01	0.01	0.01
Total coliform (TC)	16000.00	16000.00	16000.00
LPI	12.383	11.948	12.060

[±] All parameters are in mg/l except pH and total coliform (MPN/100ml)

3 RESULTS AND DISCUSSION

3.1 RESULTS

3.1.1 Principal Component Analysis

In order to facilitate the running of Principal Component Analysis (PCA), the input data from Tables 1 – 3 for the three dump sites were utilized.

Tables 4 – 6 present the results of principal component analysis for the three dump sites. For each table, we have the leachate pollution parameters and the rotated components in form of

VF1 and VF2. An interesting observation for the rotated components is the values of the correlated coefficient highlighted in '**' superscript which signified parameters to be selected for model development. Diagrammatically, Figures 3 - 6 present correlation between variables and factors and between dump sites and factors. Variables clustered together around the axes indicate component factor values with the highest correlation coefficient.

Table 4: Loadings of Leachate variables on significant principal components for Niger-Cat Dump Site

Leachate Pollution Parameters	Rotated Components [±]	
	VF1	VF2
pH	0.9602*	0.0398
TDS	0.9473*	0.0527
BOD	0.6717*	0.3283
COD	0.0316	0.9684*
NH ₃ -N	0.4175	0.5825*
Nickel (Ni)	0.6551*	0.3449
Chromium (Cr)	0.0949	0.9051*
Total iron (Fe)	0.7021*	0.2979
Lead (Pb)	0.2856	0.7144*
Copper (Cu)	0.8569*	0.1431
Zinc (Zn)	0.2493	0.7507*
Phenol	0.0000	0.0000
Total coliform (TC)	0.0000	0.0000
Eigenvalue	9.5341	1.4659
Variability (%)	86.6737	13.3263
Cumulative %	86.6737	100.0000

[±]Principal Components after Varimax Rotation; *High correlation coefficient values that corresponds to selected leachate pollution parameters

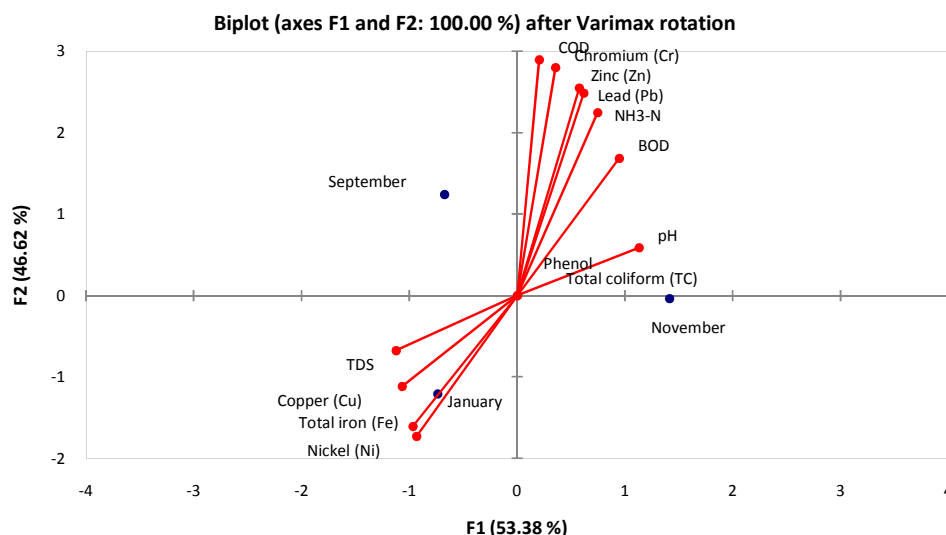


Figure 3: Biplot of correlation between observations (sample months) and factors on correlation between variables (leachate parameters) and factors after Varimax Rotation for factor loading of Niger-Cat Dump Site

Table 5: Loadings of Leachate variables on significant principal components for Don-Parkar Dump Site

Leachate Pollution Parameters	Rotated Components $\pm$	
	VF1	VF2
pH	0.9771*	0.0229
TDS	0.8613*	0.1387
BOD	0.7312*	0.2688
COD	0.7349*	0.2651
NH ₃ -N	0.0750	0.9250*
Nickel (Ni)	0.7619*	0.2381
Chromium (Cr)	0.1019	0.8981*
Total iron (Fe)	0.8235*	0.1765
Lead (Pb)	0.1475	0.8525*
Copper (Cu)	0.7693*	0.2307
Zinc (Zn)	0.6560*	0.3440
Phenol	0.0000	0.0000
Total coliform (TC)	0.0000	0.0000
Eigenvalue	9.3761	1.6239
Variability (%)	85.2377	14.7623
Cumulative %	85.2377	100.0000

[‡]Principal Components after Verimax Rotation; *High correlation coefficient values that corresponds to selected leachate pollution parameters

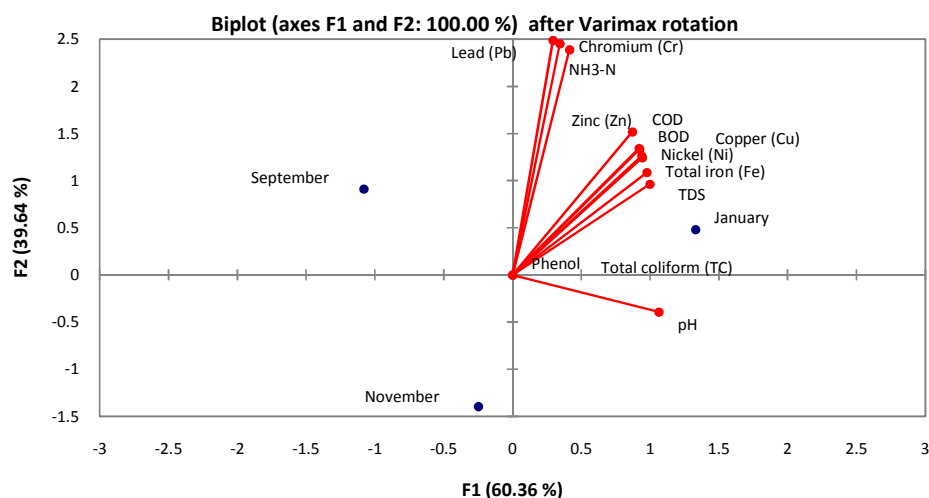


Figure 4: Bi-plot of correlation between observations and factors on correlation between variables and factors after Varimax Rotation for factor loading of Don-Parkar Dump Site

Table 6: Loadings of Leachate variables on significant principal components for Orhuwhorun Dump Site

Leachate Pollution Parameters	Rotated Components ±	
	VF1	VF2
pH	0.9961*	0.0039
TDS	0.9545*	0.0455
BOD	0.9435*	0.0565
COD	0.4402	0.5598*
NH ₃ -N	0.9975*	0.0025
Nickel (Ni)	0.9676*	0.0324
Chromium (Cr)	0.4362	0.5638*
Total iron (Fe)	0.9679*	0.0321
Lead (Pb)	0.0844	0.9156*
Copper (Cu)	0.9899*	0.0101
Zinc (Zn)	0.1070	0.8930*
Phenol	0.0000	0.0000
Total coliform (TC)	0.0000	0.0000
Eigenvalue	7.8857	3.1143
Variability (%)	71.6882	28.3118
Cumulative %	71.6882	100.0000

*Principal Components after Verimax Rotation; *High correlation coefficient values that corresponds to selected leachate pollution parameters

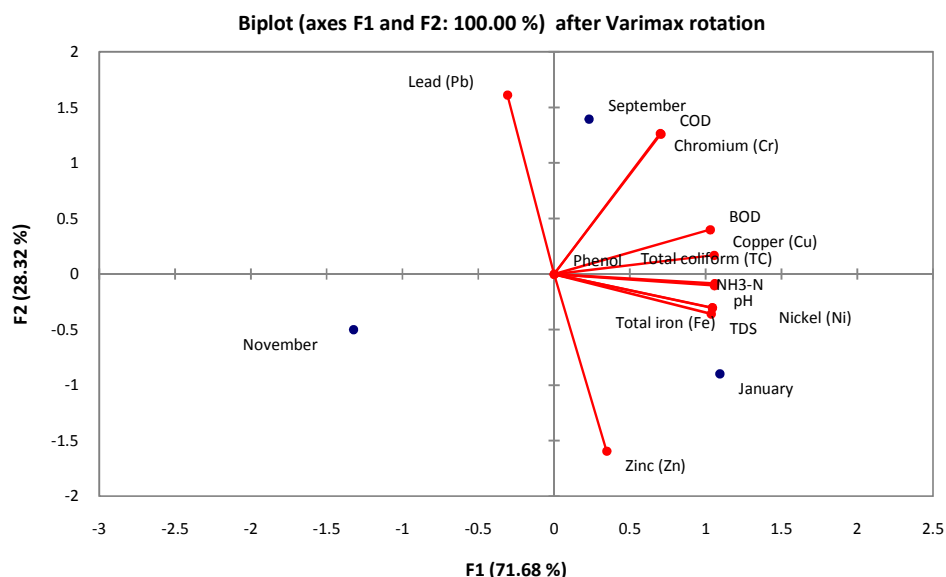


Figure 5: Biplot of correlation between observations and factors on correlation between variables and factors after Varimax Rotation for factor loading of Niger-Cat Dump Site

3.1.2 Leachate Pollution Index Models

For the purpose of model development, the leachate pollution parameters with the highest correlation coefficient were selected (see Tables 4 – 6). For each dump site, two models were simulated viz; Niger-Cat, we have model-1 with six (6) independent variables namely pH, TDS, BOD, Nickel, Iron and Copper, and model-2 with five (5) independent variables namely COD, Ammonia, Chromium, Lead and Zinc. Similarly, for Don-Parkar, model-1 has eight (8) independent variables namely pH, TDS, BOD, COD, Nickel, Iron, Copper and Zinc, and model-2 with three (3) independent variables namely Ammonia, Chromium and Lead. Also, Orhuwhorun dump site has model-1 with seven (7) independent variables namely pH, TDS, BOD, Ammonia, Nickel, Iron and Copper, and model-2 with four (4) independent variables namely COD, Chromium, Lead and Zinc, respectively.

The simulated models with their corresponding R^2 values are as presented in Tables 7. On the basis of higher R^2 values for each modelled dump site, the selected models are as presented in Table 8.

231 **Table 7:** Model Development for Leachate Pollution Index

Extracted Factors	Model	Coefficient of Variance, R^2	Remark
1) Niger-Cat Dump Site			
VF1	$f(x1, x2, x3, x4, x5, x6)$	0.4002	Model Rejected
VF2	$f(x1, x2, x3, x4, x5)$	0.9555	Model Accepted
2) Don-Parkar Dump Site			
VF1	$f(x1, x2, x3, x4, x5, x6, x7, x8)$	0.9865	Model Accepted
VF2	$f(x1, x2, x3)$	0.6012	Model Rejected
3) Orhuwhorun Dump Site			
VF1	$f(x1, x2, x3, x4, x5, x6, x7)$	0.1250	Model Rejected
VF2	$f(x1, x2, x3, x4)$	0.9575	Model Accepted

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233

234 **Table 8:** Selected Leachate Pollution Index (LPI) Models

SITES MODEL EQUATION	R^2 - Value
1. NIGER-CAT $y = 12.081 + 1.47 \times 10^{-3}x_1 + 1.396 \times 10^{-2}x_2 + 1.1901x_3 + 4.3559 \times 10^{-1}x_4 + 1.3784 \times 10^{-1}x_5$ where, y = Leachate Pollution Index, x_1 = Chemical Oxygen Demand, x_2 = Ammonia, x_3 = Chromium, x_4 = Lead, x_5 = Zinc	0.9555
2. DON-PARKAR $y = 10.347 + 2.669 \times 10^{-1}x_1 + 2.2 \times 10^{-4}x_2 + 2.11 \times 10^{-3}x_3 + 9.3 \times 10^{-4}x_4 + 3.1204x_5 + 4.064 \times 10^{-2}x_6 + 1.1716x_7 + 5.814 \times 10^{-2}x_8$ where y = Leachate Pollution Index, x_1 = pH, x_2 = Total Dissolved Solids, x_3 = Biochemical Oxygen Demand, x_4 = Chemical Oxygen Demand, x_5 = Nickel, x_6 = Iron, x_7 = Copper, x_8 = Zinc	0.9865
3. ORHUWHORUN $y = 11.5373 + 7.69 \times 10^{-3}x_1 + 4.5558 \times 10^{-1}x_2 + 1.9421 \times 10^{-1}x_3 - 1.2567 \times 10^{-1}x_4$ where, y = Leachate Pollution Index, x_1 = Chemical Oxygen Demand, x_2 = Chromium, x_3 = Lead, x_4 = Zinc	0.9575

235 Figure 6 presents the observed LPI and predicted LPI values of developed models for Niger-

236 Cat, Don-Parkar and Orhuwhorun dump sites for sake of comparison.

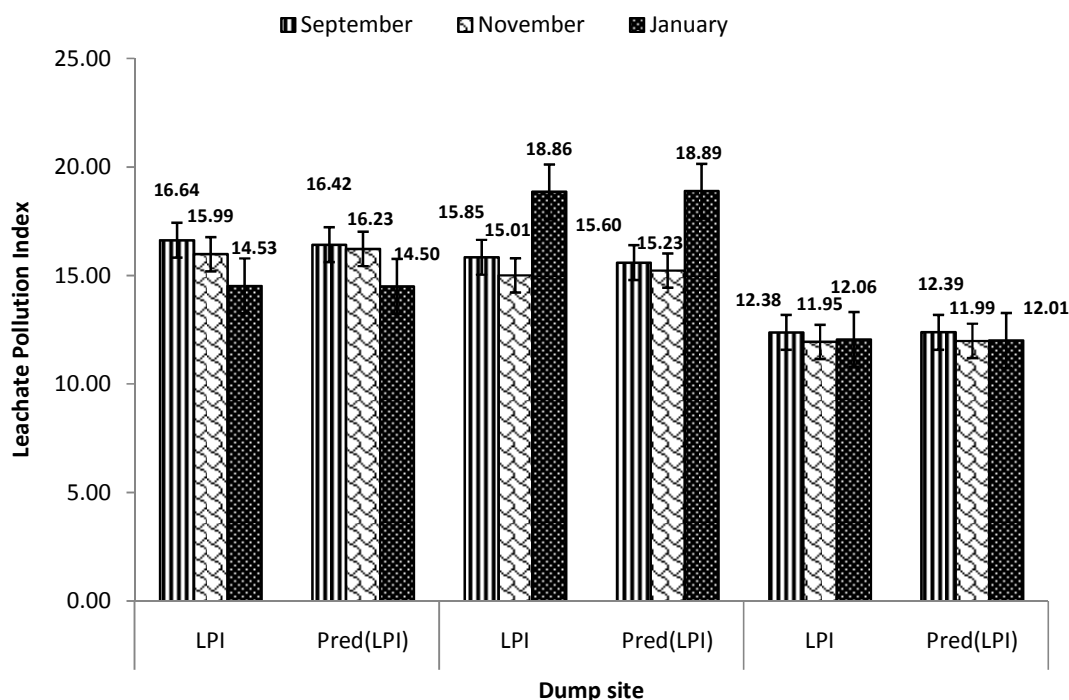


Figure 6: Modelled LPI values against Observed LPI values

3.2 DISCUSSION

3.2.1 Principal Component Analysis

From the principal component analysis results, the number of significant factor components were determined based on both scree plots (see Figures A1 – A3) and eigenvalues (see Tables 4 – 6). The eigenvalue criterion indicates that factor components with eigenvalues higher than one are regarded as significant. In this study, PCA extracted two significant Principal Factors (F1 and F2) with eigenvalues > 1 , explaining 100% of the total cumulative variability in the data sets from the dump sites (see Tables 4 – 6). Varimax rotation was performed on extracted factors to improve the interpretation of PCA, as it increased the absolute values of larger loadings and reduced the absolute values of smaller loadings within each component.

The factor loadings is classified as Strong, Moderate, and Weak corresponding to absolute loading values of > 0.75 , $(0.50 - 0.75)$ and $(0.30 - 0.50)$, respectively [28]. VF1 and VF2 accounted for 86.7 and 13.3% of the total variance for Niger-Cat, respectively. For Don-Parkar, VF1 and VF2 accounted for 85.2% and 14.8% of the total variance, respectively.

ForOrhuwhorun, VF1 and VF2 accounted for 71.7 and 28.3% of the total variance, respectively.

Principal Component Analysis (PCA) affords data reduction with minimum loss of information. PCA was used to extract the most important parameters from the thirteen (13) leachate pollution parameters from each dump site. After Varimax rotation, six (6) important parameters were extracted for model development for Niger-Cat, eight (8) for Don-Parkar and four (4) for Orhuwhorun dump site, respectively. The best models for the three dump sites were selected based on “Goodness of Fit” (coefficient of variance, R^2) value (see Table 7). A multiple linear regression simulation using XLSTAT 2016 (version 6) was run for Factors 1 and 2 after Varimax rotation (i.e. VFI and VF2) for each dump site. The model with the higher R^2 was selected for each dump site (see Table 8). The advantage gained with VFI and VF2 with respect to R^2 model selection is that the selected models offered better prediction of leachate pollution index with minimum residuals.

Leachate Pollution Index (LPI)

The output on the application of the weighted additive leachate pollution index (using Equation 2) on the collected data taking $m = 13$ and $\sum w_i = 0.718$ are presented in Tables A1 – A3 for the pollution index for Niger-Cat, Don-Parkar and Orhuwhorun dump sites, respectively.

Parameters like mercury, arsenic, cyanide, chlorides and Total Kjeldahl Nitrogen values were not determined during field study and as such, were not considered in computing the leachate pollution index for the three dump sites.

At Niger-Cat dump site, the concentration of leachate parameters such as TDS (2877.33mg/l, 2066.00mg/l and 3100.00mg/l), BOD_5 (397.10mg/l, 444.03mg/l and 327.43mg/l), COD (1020.33mg/l, 916.67mg/l and 737.33mg/l) and lead (0.96mg/l, 0.98mg/l and 0.11mg/l) exceeded the leachate disposal standards (see Table A1, column 3) during the sampling period of September, November and January. The concentration of ammonia (54.9mg/l, 59.54 and 31.22mg/l) and zinc (7.06mg/l, 6.98mg/l and 4.28mg/l) were found to have exceeded the permissible limit in the month of September and November. Ammonia and zinc were within limit in January. Phenol, nickel, chromium and copper were within the permissible limit throughout the sampling periods. pH (6.97, 7.89 and 6.69) for September, November and January were within specified limit (5.5 – 9.0), although November accounted for the highest pH.

At Don-Parkar dump site, leachate parameters such as TDS (3373.33mg/l, 3290.00mg/l and 5426.67mg/l), BOD₅ (358.47mg/l, 309.47mg/l and 545.60mg/l), COD (816.00mg/l, 707.00mg/l and 1242.67mg/l), ammonia (74.41mg/l, 60.58mg/l and 76.12mg/l) and lead (0.88mg/l, 0.62mg/l and 0.96mg/l) have concentration values higher than the maximum permissible limit (see Table A2, column 3) for September, November and January. TDS was twice higher than standard in January. Zinc (5.77mg/l, 3.31mg/l and 11.97mg/l) was found to have exceeded the disposal standards in September and January, while zinc was within the specified standard in November. pH (6.37, 7.15 and 8.01) was within permissible limit throughout sampling periods. The concentration of phenol, nickel, chromium and copper were within specified limit of leachate disposal standards.

At Orhuwhorun dump site, the concentration of BOD₅ (69.17mg/l, 63.17mg/l and 70.07mg/l) and lead (0.82mg/l, 0.45mg/l and 0.16mg/l) exceeded the permissible limit (see Table A3, column 3) for the period of September, November and January. The pH value (6.90, 6.44 and 7.22) for September, November and January was within the permissible limit while the concentration of TDS, COD, ammonia, phenol, nickel chromium copper and zinc were below the maximum permissible limit.

3.2.2 Modelled and Observed LPI values

A graphical illustration of modelled LPI values and their corresponding observed LPI values for each dump site is presented in Figure 6. The modelled LPI values were 16.4216, 16.2279 and 14.5037 while the observed values 16.6365, 15.9889 and 14.5279 at Niger-Cat dump site. The highest LPI value occurred in September. The trend was 16.4216>16.2279>14.5037 for September, November and January respectively. At Don-Parkar dump site, the modelled LPI values were 15.5983, 15.2307 and 18.8870 while the observed values 15.8454, 15.0084 and 18.8621. The highest LPI value occurred in January while November accounted for the lowest LPI value. The modelled LPI values were 12.3852, 11.9939 and 12.0123 while the observed LPI values 12.3830, 11.9485 and 12.0599 at Orhuwhorun dump site. The lowest LPI value was accounted for in November, followed by January, while September had the highest LPI value.

The comparison of LPI values for all dump sites indicated that Don-Parkar had the highest (average) LPI value, while Orhuwhorun dump site accounted for the lowest LPI value. The LPI values of the three dump sites were above the LPI standard value of 7.378 [14]. The lower LPI value at Orhuwhorun dump site indicates a relatively lower contamination potential compared to that of Niger-Cat and Don-Parkar. Niger-Cat and Don-

Parkar LPI values were twice higher than the leachate pollution index standard as at the time of this study. This indicates the leachates from these dump sites were of very high pollution potential and pose great threats to the environment.

4 CONCLUSION

Models for predicting Leachate Pollution Index (LPI) of Niger-Cat, Don-Parkar and Orhuwhorun dump sites were developed in this study. The LPI is a very useful tool for assessing and monitoring the pollution potentials of leachate generated from dump site. This study has shown that Niger-Cat, Don-Parkar and Orhuwhorun dump sites are threats to local surface and groundwater of the study area and to a wider population with passage of time if left unattended to.

5 RECOMMENDATION

This study had revealed that Niger-Cat, Don-Parkar and Orhuwhorun dump sites are sources of environmental pollution and pose a threat to groundwater as a result of leachate migration. Therefore, the following recommendations are made:

1. Effort should be made and measures put in place to curtail the threats posed by the three dump sites to surface water and groundwater by way of providing systems for leachate collection and treatment.
2. Prioritized order of attention should be given first to Don-Parkar site followed by Niger-Cat site and then Orhuwhorun dump site, respectively.

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APPENDIX A

Table A1: Characteristics and Observed Pollution Index of Niger-Cat Dump Site Leachate

S/N	Parameter ±	Leachate Disposal Standards*	Weight (w _i)	Parameter concentration			Sub Index Rating (p _i)			Cumulative pollution rating (p _{wi})		
				Sep	Nov	Jan	Sep	Nov	Jan	Sept	Nov	Jan
1	pH	5.5 - 9.0	0.055	6.97	7.89	6.69	5	5	5	0.275	0.275	0.275
2	TDS	2100	0.05	2827.33	2066	3100	9	6	10	0.45	0.3	0.5
3	BOD	30	0.061	397.10	444.03	327.43	20	20	10	1.22	1.22	0.61
4	COD	250	0.062	1020.33	916.67	737.33	35	30	30	2.17	1.86	1.86
5	NH ₃ -N	50	0.051	54.90	59.54	31.22	8	9	5	0.408	0.459	0.255
6	Mercury	0.01	-	-	-	-	-	-	-	-	-	-
7	Phenol	0.1	0.057	0.01	0.01	0.01	5	5	5	0.285	0.285	0.285
8	Nickel (Ni)	3	0.052	0.15	0.14	0.17	5	5	5	0.26	0.26	0.26
9	Chromium	2	0.064	0.57	0.49	0.23	6	6	5	0.384	0.384	0.32
10	Arsenic	0.2	-	-	-	-	-	-	-	-	-	-
11	Cyanide	0.2	-	-	-	-	-	-	-	-	-	-
12	Total iron	-	0.045	6.43	3.94	9.71	5	5	5	0.225	0.225	0.225
13	Chlorides	100	-	-	-	-	-	-	-	-	-	-
14	TKN	100	-	-	-	-	-	-	-	-	-	-
15	Lead	0.1	0.063	0.96	0.98	0.11	10	10	5	0.63	0.63	0.315
16	Copper	3	0.05	0.19	0.17	0.21	5	5	5	0.25	0.25	0.25
17	Zinc	5	0.056	7.06	6.98	4.28	8	7	6	0.448	0.392	0.336
18	Total coliform	-	0.052	16000	16000	16000	95	95	95	4.94	4.94	4.94
Total			0.718							11.945	11.48	10.431
LPI										16.636	15.989	14.528

± All parameters are in mg/l except pH and total coliform (MPN/100ml)

*Indian leachate disposal standards (Kumar et al., 2003)

Table A2: Characteristics and Observed Pollution Index of Don-Parkar Dump Site Leachate

S/N	Parameter ±	Leachate Disposal Standards	Weight (w _i)	Parameter concentration			Sub Index Rating (p _i)			Cumulative pollution rating (p _i w _i)		
				Sep	Nov	Jan	Sep	Nov	Jan	Sep	Nov	Jan
1	pH	5.5 - 9.0	0.055	6.37	7.15	8.01	5	5	5	0.275	0.275	0.275
2	TDS	2100	0.05	3373.33	3290.00	5426.67	10	10	12	0.5	0.5	0.6
3	BOD	30	0.061	358.47	309.47	545.60	13	12	20	0.793	0.732	1.22
4	COD	250	0.062	816.00	707.00	1242.67	32	30	55	1.984	1.86	3.41
5	NH ₃ -N	50	0.051	74.41	60.58	76.12	9	8	9	0.459	0.408	0.459
6	Mercury	0.01	-	-	-	-	-	-	-	-	-	-
7	Phenol	0.1	0.057	0.01	0.01	0.01	5	5	5	0.285	0.285	0.285
8	Nickel (Ni)	3	0.052	0.13	0.10	0.26	5	5	5	0.26	0.26	0.26
9	Chromium	2	0.064	0.53	0.23	0.58	6	5	6	0.384	0.32	0.384
10	Arsenic	0.2	-	-	-	-	-	-	-	-	-	-
11	Cyanide	0.2	-	-	-	-	-	-	-	-	-	-
12	Total iron	-	0.045	9.03	7.90	19.68	5	5	6	0.225	0.225	0.27
13	Chlorides	100	-	-	-	-	-	-	-	-	-	-
14	TKN	100	-	-	-	-	-	-	-	-	-	-
15	Lead	0.1	0.063	0.88	0.62	0.96	10	7	10	0.63	0.441	0.63
16	Copper	3	0.05	0.17	0.10	0.52	5	5	5	0.25	0.25	0.25
17	Zinc	5	0.056	5.77	3.31	11.97	7	5	10	0.392	0.28	0.56
18	Total coliform	-	0.052	16000	16000	16000	95	95	95	4.94	4.94	4.94
Total			0.718							11.377	10.776	13.543
LPI										15.845	15.008	18.862

[±] All parameters are in mg/l except pH and total coliform (MPN/100ml)

Table A3: Characteristics and Observed Pollution Index of Orhuwhorun Dump Site Leachate

S/N	Parameter ±	Leachate Disposal Standards	Weight (w _i)	Parameter concentration			Sub Index Rating (p _i)			Cumulative pollution rating (p _i w _i)		
				Sep	Nov	Jan	Sep	Nov	Jan	Sep	Nov	Jan
1	pH	5.5 - 9.0	0.055	6.90	6.44	7.22	5	5	5	0.275	0.275	0.275
2	TDS	2100	0.05	950	780	1153.33	5	5	5	0.25	0.25	0.25
3	BOD	30	0.061	69.17	63.17	70.07	8	7	8	0.488	0.427	0.488
4	COD	250	0.062	92.83	76.33	85.13	8	7	7.5	0.496	0.434	0.465
5	NH ₃ -N	50	0.051	33.09	18.28	43.03	5	5	6	0.255	0.255	0.306
6	Mercury	0.01	-	-	-	-	-	-	-	-	-	-
7	Phenol	0.1	0.057	0.01	0.01	0.01	5	5	5	0.285	0.285	0.285
8	Nickel (Ni)	3	0.052	0.11	0.06	0.17	5	5	5	0.26	0.26	0.26
9	Chromium	2	0.064	0.44	0.16	0.31	5	5	5	0.32	0.32	0.32
10	Arsenic	0.2	-	-	-	-	-	-	-	-	-	-
11	Cyanide	0.2	-	-	-	-	-	-	-	-	-	-
12	Total iron	-	0.045	1.68	1.20	2.19	5	5	5	0.225	0.225	0.225
13	Chlorides	100	-	-	-	-	-	-	-	-	-	-
14	TKN	100	-	-	-	-	-	-	-	-	-	-
15	Lead	0.1	0.063	0.82	0.45	0.16	9	6	5	0.567	0.378	0.315
16	Copper	3	0.05	0.15	0.06	0.18	5	5	5	0.25	0.25	0.25
17	Zinc	5	0.056	1.79	2.32	2.79	5	5	5	0.28	0.28	0.28
18	Total coliform	-	0.052	16000	16000	16000	95	95	95	4.94	4.94	4.94
Total			0.718							8.891	8.579	8.659
LPI										12.383	11.948	12.060

[±] All parameters are in mg/l except pH and total coliform (MPN/100ml)

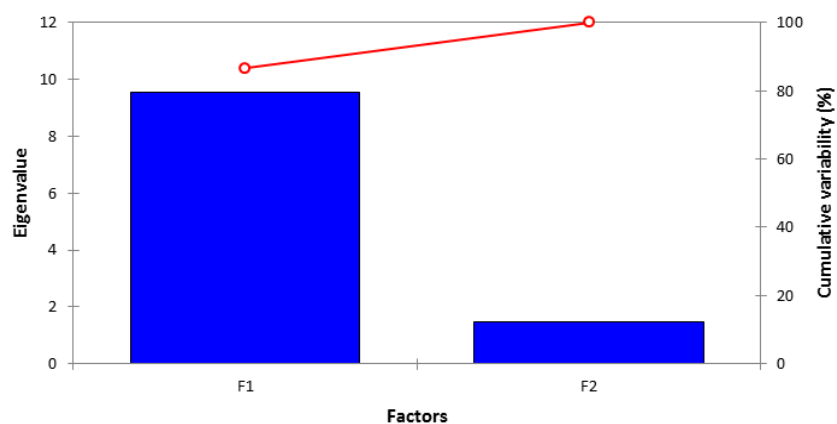


Figure A1: Scree plot for factor extraction among Niger-Cat parameters for September, November and January

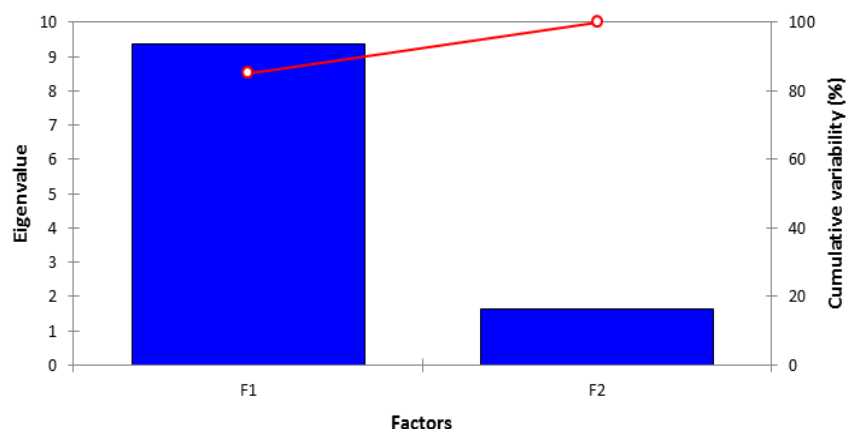


Figure A2: Scree plot for factor extraction among Don-Parkar parameters for September, November and January

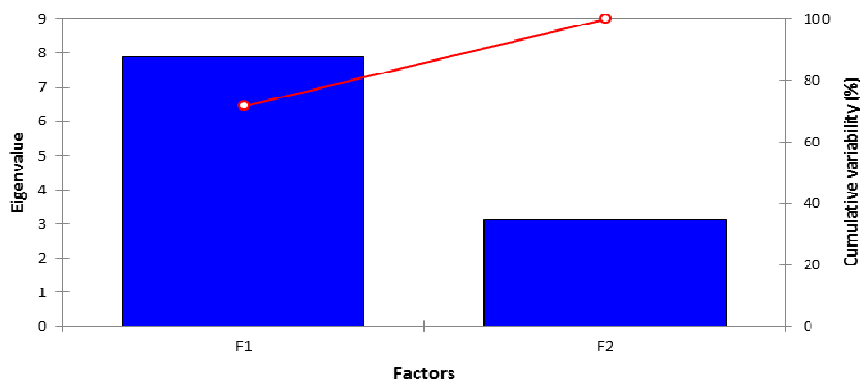


Figure A3: Scree plot for factor extraction among Orhuwhorun parameters for September, November and January