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Multivariate Statistical Approach in Modeling Surface and Groundwater Quality near Municipal Solid Waste Dump Sites in Warri Metropolitan City

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Authors' contributions

This work was carried out in collaboration between both authors. Author MO managed the literature survey, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Author ILN served as major Ph.D supervisor, guided the design of the study, managed the analysis of the study and approved the final manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Water sources are usually polluted by waste generated by human activities. This work examined the activities on three dump sites on surface and groundwater quality in Warri metropolis. Water samples from boreholes, dug-wells and stream sources around Niger-Cat, Don-Parkar and Orhuwhorun dump sites were assessed for their water quality. Purposive sampling technique was employed in the collection of water samples for the sampling period of September, November and January and the concentration of water quality parameters were determined. Principal Component Analysis (PCA) and Multiple Linear Regression (MLR) were applied to simulate Water Quality Index (WQI) models for the monitoring and prediction of water quality of groundwater and surface water around the dump sites. The models yielded goodness of fit (R^2) values which ranged from 0.9997 to 0.9999 (99%). The modeled WQI values for Boreholes: BH1, BH2 and BH3 were 60.9, 8.2 and 41.8, while Dug-wells: DW1, DW2 and DW3 were 208.2, 49.3 and 51.5 at Niger-Cat. BH1, BH2 and BH3 were 15.5, 30.8 and 36.6, while DW1 and DW2 were 30.2 and 38.4

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for Don-Parkar. For Orhuwhorun dump site, BH1 and BH2 were 33.5 and 16.2; DW1, DW2 and DW3 were 49.7, 40.4 and 21.4, while Stream SM1 was 8.7. Findings revealed that waters of the three dump sites were acidic and the quality ranged from excellent quality to unsuitable for drinking.

Keywords: Water quality index (WQI); principal component analysis; multiple linear regression; dump site; modeling, groundwater; surface water.

1. INTRODUCTION

Water is an indispensible natural resource for humans and indeed all other living organisms. The usability of water by humans is a function of its quality. Water sources are usually polluted by waste generated by human activities. According to the World Health Organization [1], safe water refers to water that does not contain harmful chemical substances or micro-organisms in concentrations that cause illness in any form. The available water sources throughout the world are becoming depleted and this problem is aggravated by the population growth rate and subsequent increase in water demand especially in developing countries.

One of the major threats to surface water and groundwater contamination is landfills [2]. More than 90% of municipal solid waste (MSW) generated in Nigeria is directly disposed on land and non-sanitary landfills in an unscientific manner that poses great danger to human and the environment [3]. If the landfill is unlined, leachate produced can easily percolate through the soil into the groundwater or run-off into surface water thereby contaminating both the groundwater and surface water [4].

The contamination of potable water in developing countries has been widely reported [5-10].

The objective of this study is to assess if the generated leachate from the dump sites is having impact on the quality of surrounding surface and groundwater near Niger-Cat, Don-Parkar and Orhuwhorun dump sites. This is achieved by determining their WQI and also, to develop models using new approaches for prediction of WQI and effective monitoring of water quality.

2. METHODOLOGY

2.1 Study Area

Warri Metropolis in this study refers to the Warri-Effurun communities. It is located within the Niger Delta in the southern part of Nigeria. It lies within the latitude and longitude 5°32'N to 5°40'N and 5° 42'E to 5° 50'E respectively, covering an area of about 499.81 km^2. The study area is represented by three dump site locations in Warri metropolis. They are Niger-Cat; the Don-Parkar and Orhuwhorun dump sites. The detailed description of the study area has been discussed in literature [11,12]. Fig. 1 shows the satellite view of Warri metropolis with the location of the three dump sites. Figs. 2 - 4 show the satellite view of Niger-Cat, Don-Parkar and Orhuwhorun dump sites.

2.2 Data Collection

The method employed for data collection is the purposive sampling technique. Water samples were collected from existing groundwater and surface water sources around Niger-Cat, Don-Parkar and Orhuwhorun dump sites. A total of fifty-one (51) water samples were collected between the three dump sites for laboratory analysis for the period of September and November, 2015 and January, 2016. Samples were collected in 1-litre polyethylene bottles which were pretreated prior to sampling.

At Niger-Cat dump site, a total of eighteen (18) water samples were collected from six (6) existing sources (3 boreholes and 3 dug-wells). Borehole samples were designated as Borehole-1 (BH1), Borehole-2 (BH2) and Borehole-3 (BH3), while Dug-well samples were designated as Dug-well-1 (DW1), Dug-well-2 (DW2) and Dug-well-3 (DW3), respectively.

At Don-Parkar dump site, a total of fifteen (15) water samples were collected from five (5) existing water sources (3 boreholes and 2 dug-wells). Borehole samples were designated as Borehole-1 (BH1), Borehole-2 (BH2) and Borehole-3 (BH3), while dug-wells were designated as Dug-well-1 (DW1) and Dug-well-2 (DW2), respectively.

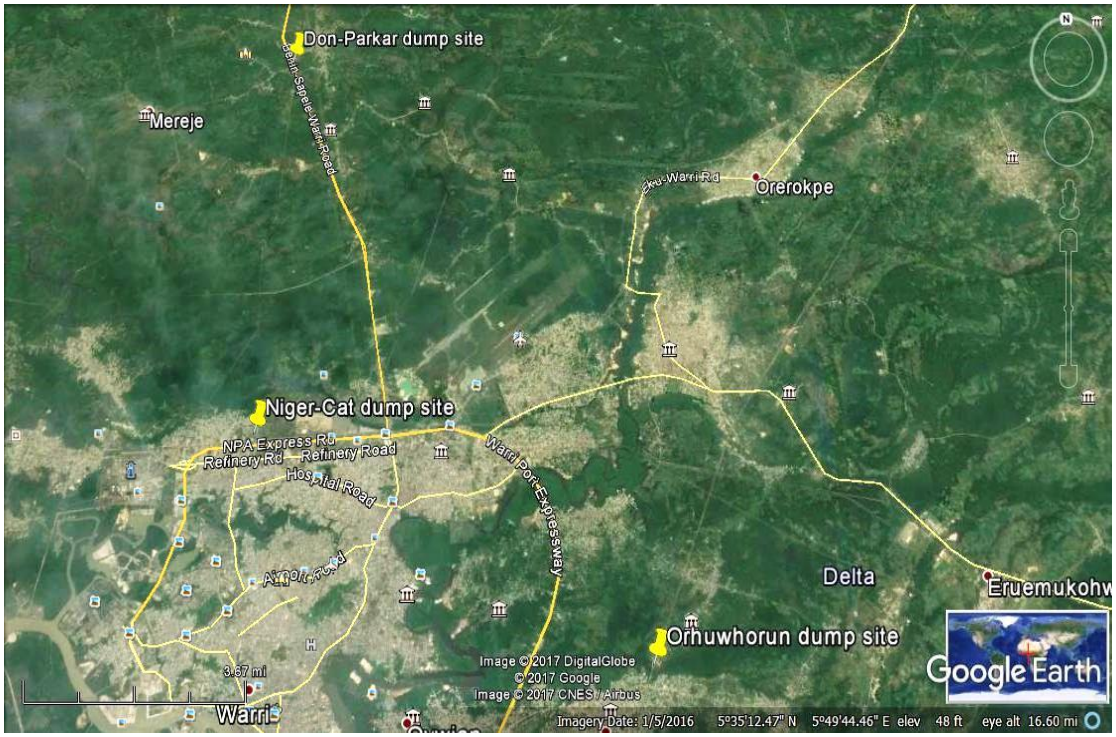


Fig. 1. Map of Warri metropolis showing the location of the three dump sites in yellow pins

Fig. 2. Satellite Image of Niger-Cat dump site

Fig. 3. Satellite Image of Don-Parkar dump site

Fig. 4. Satellite Image of Orhu who run dump site

At Orhuwhorun dump site, a total of eighteen (18) water samples were collected from six (6) existing water sources (2 boreholes, 3 dug-wells and 1 stream). Borehole samples were designated as Borehole-1 (BH1) and Borehole-2 (BH2), dug-well samples were designated as Dug-well-1 (DW1), Dug-well-2 (DW2) and Dug-well-3 (DW3), while stream sample was designated as Stream-1 (SM1), respectively. All water sources are within 415 metre radius of the dump site (see Table A5). Sampling locations were geo-referenced using Global Positioning System (GPS) device known as Garmin GPSmap76CSx.

2.3 Data Analysis

The methods employed in the analysis of generated raw data for the determination of water quality around the dump sites were the Weighted Arithmetic Water Quality Index (WAWQI), Principal Component Analysis (PCA) coupled with Multiple Linear Regression (MLR). PCA was employed to extract the principal water quality parameters, while MLR was adopted for model development using the extracted water quality parameters.

2.3.1 Analytical method

The following three parameters pH, conductivity and turbidity were monitored at the sampling sites and other parameters like total dissolved solids, total hardness, nitrate, magnesium, chloride, sulphate, sodium, zinc and iron were analyzed in the laboratory as per the standard procedures specified by the American Public Health Association [13].

2.3.2 Water quality index method

Water quality index (WQI) provides a single number that expresses the general water quality at a certain location and time based on several water quality parameters. The goal of WQI is to transform numerous water quality data into information that is understandable and usable by the public. Basically, a WQI attempts to provide a mechanism for presenting a cumulatively derived, numerical expression defining a certain level of water quality [14]. A single WQI value makes information much more easily understood than a long list of numerical values for a large variety of parameters.

2.3.2.1 Parameter selection

To calculate WQI of groundwater and surface water quality around the three dump sites, twelve (12) physico-chemical water parameters were selected according to standards [15-19]. The WQI was calculated using standards of drinking water quality recommended by the World Health Organization [16] (see Table A1).

The weighted Arithmetic Water Quality Index [20] was used for the calculation of WQI in this study. The calculation of WQI was made using Equation (1):

$$WQI = \frac{\Sigma Q_j W_j}{\Sigma W_j} \quad (1)$$

The quality rating scale (Q_j) for each parameter is calculated via Equation (2):

$$Q_j = \left[\frac{V_j - V_0}{S_j - V_0}\right] \times 100 \quad (2)$$

where, V_j is the estimated concentration of the jth parameter in the analyzed water;

V_o is the ideal value of this parameter in pure water which is usually zero except $pH = 7.0$ and $DO = 14.6\ mg/l$); and

S_j is the recommended standard value of jth parameter.

The unit weight (W_j) for each water quality parameter is calculated by using Equation (3):

$$W_j = \frac{K}{S_j} \quad (3)$$

Where; K = proportionality constant and can also be calculated by Equation (4):

$$K = \frac{1}{\Sigma(\frac{1}{S_j})} \quad (4)$$

The WQI rating is as presented in Table 1.

Table 1. Water quality rating as per weighted arithmetic water quality index [21]

WQI value	Rating of water quality	Grade
0 – 25	Excellent	A
26 – 50	Good	B
51 – 75	Poor	C
76 – 100	Very poor	D
Above 100	Unsuitable for drinking purpose	E

2.3.3 Principal component analysis (PCA)

PCA is a multivariate statistical method that provides information on the most significant parameters that describe the majority of the data set, affording data reduction with minimum loss of original information [22]. PCA transforms a data set (independent variables) into an orthogonal basis called Principal Components (PC), which are linear combinations of the original variables. Principal Component Regression (PCR) is a function in XLSTAT that does PCA and Multiple Linear Regression (MLR) together. That is, PCR extracts the principal component of the independent variables and also does regression on the extracted principal components automatically [11], but PCA on its merit only extract the principal components without running a regression analysis [23]. Equation (5) presents the basic equation for PC [24].

$$Q_{jk} = a_{j1}x_{1k} + a_{j2}x_{2k} + a_{j3}x_{3k} + \cdots + a_{jm}x_{mk} \quad (5)$$

Where *Q* is the component score, a is the component loading, *x* is the measured value of variable, *j* is the component number, *k* is the sample number and m is the total number of variables.

2.3.4 Multiple linear regression (MLR)

A linear regression is a statistical approach for modeling the relationship between a dependent variable and one or more independent variables. A simple linear regression model is of the form:

$$y = a_0 + a_1 x \quad (6a)$$

However, analysis of linear regression (Equation 6a) can be extended to a situation in which the dependent variable *y* is affected by several independent variables. A corresponding linear but multiple regression model is of the form [25]:

$$y_i = a_0 + a_1 x_{i1} + a_2 x_{i2} + a_3 x_{i3} + \cdots + a_n x_{in} \quad (6b)$$

Where y_i = WQI (dependent variable) *and* x_i= significant water parameters (independent variables)

Table 2. Water Quality Input Data for WQI model development for Niger-Cat dump site

Parameters ±	BH1	BH2	BH3	DW1	DW2	DW3
pH	5.08	5.567	4.757	6.813	6.803	3.98
TDS	143.7	8.333	78.667	513.7	105	94.67
Conductivity	258.7	15.667	142.067	924.3	188.9	170.1
Turbidity	1.043	1.02	1.953	1.37	2.873	2.733
T. Hardness	72.77	3.643	24.57	128.5	39.43	34.7
Nitrate	0.28	0.009	0.173	0.613	0.32	0.2
Sulphate	1.273	0.14	2.097	5.713	3.533	2.627
Chloride	82.09	3.147	20.45	220.4	34.94	29.89
Magnesium	7.843	0.373	1.84	53.73	4.153	3.143
Sodium	2.01	0.117	1.06	20.31	1.66	1.24
Zinc	0.247	0.102	0.159	2.847	0.205	0.185
Iron	0.201	0.015	0.127	0.72	0.165	0.154

±All parameters are in mg/l except pH, WQI, Conductivity (µS/cm) and Turbidity (NTU).
All values are mean values of triplicate samples.

Table 3. Water quality input data for WQI model development for Don-Parkar dump site

Parameters ±	BH1	BH2	BH3	DW1	DW2
pH	5.653	5.427	5.730	5.110	6.310
TDS	13.333	17.333	26.000	20.667	51.000
Conductivity	23.667	31.333	46.333	38.333	92.000
Turbidity	0.963	0.610	1.120	3.257	1.250
T. Hardness	5.533	8.977	12.040	9.800	24.173
Nitrate	0.009	0.023	0.040	0.036	0.100
Sulphate	0.330	0.580	0.623	0.557	0.900
Chloride	5.397	7.520	11.110	7.837	17.133
Magnesium	0.693	1.300	2.230	1.713	3.453
Sodium	1.200	0.960	1.183	0.923	1.450
Zinc	0.113	0.130	0.139	0.129	0.151
Iron	0.042	0.097	0.120	0.083	0.129

±All parameters are in mg/l except pH, WQI, Conductivity (µS/cm) and Turbidity (NTU).
All values are mean values of triplicate samples.

Table 4. Water Quality Input Data for WQI model development for Orhuwhorun dump site

Parameters ±	BH 1	BH2	DW1	DW2	DW3	SM1
pH	6.147	5.630	6.610	6.070	5.057	6.163
TDS	23.000	12.333	87.667	67.000	27.333	9.667
Conductivity	41.000	22.333	157.667	120.900	49.267	17.333
Turbidity	1.687	2.057	4.180	2.997	2.117	1.483
T. Hardness	11.450	5.917	34.150	23.333	7.080	4.250
Nitrate	0.040	0.013	0.113	0.100	0.013	0.009
Sulphate	0.637	0.303	1.017	1.723	0.827	0.180
Chloride	9.933	5.290	28.660	19.727	6.090	3.247
Magnesium	2.097	0.623	5.860	1.360	0.657	0.490
Sodium	1.120	0.190	1.720	0.983	0.460	0.130
Zinc	0.139	0.113	0.196	0.163	0.076	0.100
Iron	0.108	0.041	0.161	0.128	0.055	0.019

±All parameters are in mg/l except pH, WQI, Conductivity (µS/cm) and Turbidity (NTU).
All values are mean values of triplicate samples.

Equation (6b) is the governing equation employed for the development of the models in the study.

2.3.5 Modeling of water quality index

In order to develop the models, a statistical tool, XLSTAT 2016 (Version 6 statistical package) was used. First, the twelve (12) independent parameters (pH, COD, nickel, etc.) form the input data (see Tables 2 – 4) were subjected to PCA for identification of the principal parameters. Secondly, multiple linear regression was run between the dependent variable (observed WQI values) from the results of Equation (1) (see Table 5) and the independent variables (principal parameters).

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Water quality index

The water quality of different sampled boreholes, dug-wells and stream around the three dump sites by the application of the weighted arithmetic water quality index is as presented in Table 5.

3.1.2 Principal component analysis

To carry out the running of Principal Component Analysis (PCA), the data from Tables 2 – 4 for the three dump sites were utilized. Tables 6, 8 and 10 present the results of PCA (that is, eigenvalues and extracted factors).Varimax rotation was further applied to the results of PCA to optimize the various water quality parameters for the purpose of model development. Tables 7, 9 and 11 present the factors loadings after Varimax rotation. The rotated components (VF1 and VF2) show the correlated coefficient of the parameters. The values in bold prints represent parameters to be selected for model development. Figs. 5 – 7 are diagrammatical representations of the correlation of water sources with respect to water quality parameters against the generated factors (F1 and F2). This explains the relationship between the variables, the observed data and the extracted factors.

3.1.3 Description of models for water quality index

The most significant water quality parameters (that is, parameters with the highest correlation coefficient) were selected for the purpose of model development (see Tables 7, 9 and 11). Two WQI models (Models 1 and 2) were developed for each dump site based on the rotated factors (VF1 and VF2). At Niger-Cat dump site: Model-1 has eleven (11) independent water quality parameters, while Model-2 has just one (1).Similarly, at Don-Parkar, Model-1 has nine (9) independent parameters and Model-2 has three (3) respectively. Also at Orhuwhorun, Models-1 and 2 have eight (8) and four (4) independent parameters respectively.The developed models with their respective goodness of fit, R^2 values are presented in Table 12. Figs. 8-10 are plots of the predicted Water Quality Index against the observed with respect to the developed model performance.

Table 5. Water quality around the three dump sites ±

Source	WQI	Interpretation	Water Quality Rating (WQR)*
		a. Niger-Cat Dump Site	
BH1	60.91	Poor	3
BH2	8.20	Excellent	5
BH3	41.75	Good	4
DW1	208.18	Unsuitable for drinking	1
DW2	49.30	Good	4
DW3	51.54	Poor	3
		Total	**20 points**
		b. Don-Parkar Dump Site	
BH1	15.52	Excellent	5
BH2	30.59	Good	4
BH3	36.86	Good	4
DW1	30.16	Good	4
DW2	38.40	Good	4
		Total	**21 points**
		c. Orhuwhorun Dump Site	
BH1	33.50	Good	4
BH2	16.37	Excellent	5
DW1	49.66	Good	4
DW2	40.42	Good	4
DW3	21.29	Excellent	5
SM1	8.59	Excellent	5
		Total	**27 points**

*± Additional details on BH, DW and SM depth and distance from thedump sites are provided in Table A5. *WQR as: Excellent =5, Good = 4, Poor = 3, Very poor = 2, Unsuitable for drinking = 1.*

Table 6. Eigenvalues of extracted factors of water quality parameters for Niger-Cat

	F1	F2	F3	F4	F5
Eigenvalue	9.7971	1.3020	0.6783	0.2132	0.0095
Variability (%)	81.6424	10.8500	5.6521	1.7766	0.0790
Cumulative %	81.6424	92.4924	98.1445	99.9210	100.0000

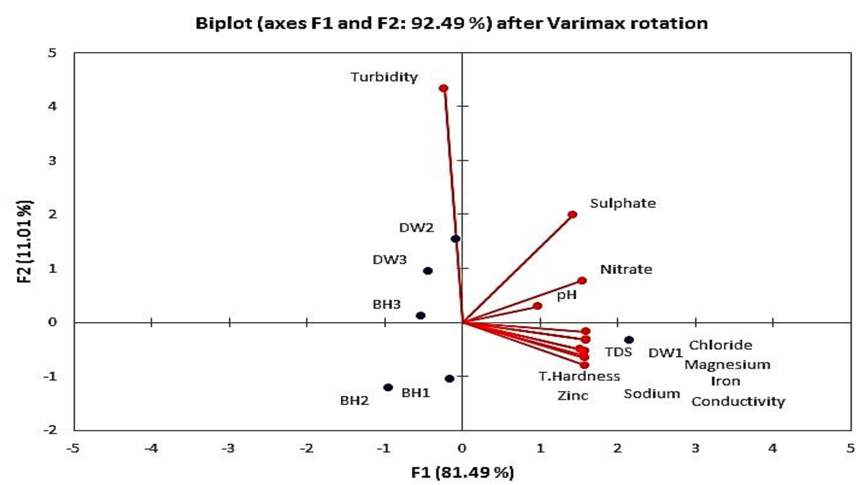


Fig. 5. Bi-plot of the correlation of water sources on water quality parameters against the generated factors (F1 and F2) at Niger-Cat

Table 7. Loadings of water quality variables on significant principal components of Niger-Cat dump site

Water quality parameters	Rotated components ±	
	VF1	**VF2**
pH	**0.3656**	0.0045
TDS	**0.9888**	0.0053
Conductivity	**0.9887**	0.0054
Turbidity	0.0203	**0.9683**
T. Hardness	**0.8949**	0.0130
Nitrate	**0.9218**	0.0305
Sulphate	**0.7892**	0.2039
Chloride	**0.9543**	0.0324
Magnesium	**0.9627**	0.0225
Sodium	**0.9590**	0.0144
Zinc	**0.9428**	0.0188
Iron	**0.9904**	0.0016

±Principal Components after Varimax rotation

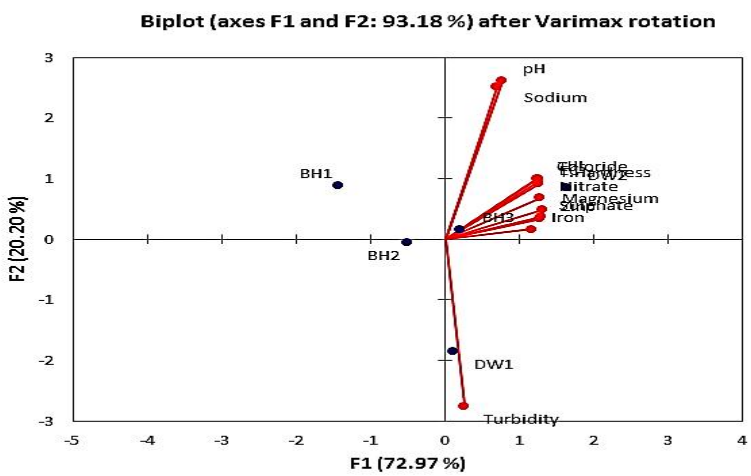


Fig. 6. Bi-plot of the correlation of water sources on water quality Parameters against the generated factors (F1 and F2)at Don-Parkar

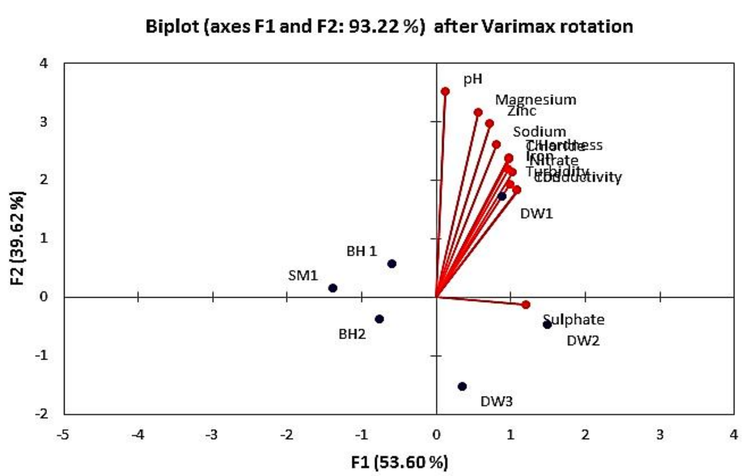


Fig. 7. Bi-plot of the correlation of water sources on water Quality parameters against the generated factors (F1 and F2) at Orhuwhorun

Table 8. Eigenvalues of extracted factors of water quality parameters for Don-Parkar

	F1	F2	F3	F4
Eigenvalue	9.5858	1.5954	0.7130	0.1059
Variability (%)	79.8813	13.2947	5.9416	0.8824
Cumulative %	79.8813	93.1760	99.1176	100.0000

Table 9. Loadings of water quality variables on significant principal components of Don-Parkar dump site

Water quality parameters	Rotated components ±	
	VF1	VF2
pH	0.3340	**0.6516**
TDS	**0.8832**	0.0957
Conductivity	**0.8921**	0.0839
Turbidity	0.0386	**0.7211**
T. Hardness	**0.9044**	0.0790
Nitrate	**0.9275**	0.0443
Sulphate	**0.9438**	0.0129
Chloride	**0.9014**	0.0967
Magnesium	**0.9705**	0.0222
Sodium	0.2732	**0.6036**
Zinc	**0.9274**	0.0109
Iron	**0.7606**	0.0025

±*Principal Components after Varimax rotation*

Table 10. Eigenvalues of extracted factors of water quality parameters for Orhuwhorun

	F1	F2	F3	F4	F5
Eigenvalue	10.0775	1.1084	0.4506	0.3029	0.0606
Variability (%)	83.9792	9.2368	3.7549	2.5239	0.5052
Cumulative %	83.9792	93.2160	96.9709	99.4948	100.0000

Table 11. Loadings of water quality variables on significant principal components of Orhuwhorun dump site

Water quality parameters	Rotated components ±	
	VF1	VF2
pH	0.0093	**0.8503**
TDS	**0.7465**	0.2329
Conductivity	**0.7488**	0.2303
Turbidity	**0.6140**	0.2561
T. Hardness	**0.6019**	0.3921
Nitrate	**0.6608**	0.3114
Sulphate	**0.9130**	0.0013
Chloride	**0.6099**	0.3857
Magnesium	0.2011	**0.6864**
Sodium	0.4099	**0.4685**
Zinc	0.3304	**0.6081**
Iron	**0.5863**	0.3310

±*Principal Components after Varimax rotation*

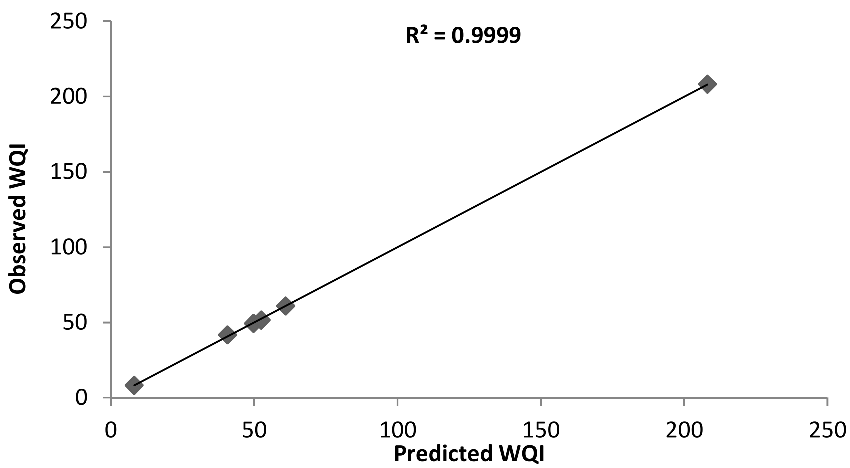
Table 12. Simulated water quality index models

Extracted factors	Model	Goodness of Fit, R^2	Remark
	1) Niger-Cat Dump Site		
VF1	$f(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11})$	0.9999	Model Accepted
VF2	$f(x_1)$	0.0276	Model Rejected

Extracted factors	Model	Goodness of Fit, R^2	Remark
	2) Don-Parkar Dump Site		
VF1	$f(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9)$	0.9997	Model Accepted
VF2	$f(x_1, x_2, x_3)$	0.1202	Model Rejected
	3) Orhuwhorun Dump Site		
VF1	$f(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8)$	0.9999	Model Accepted
VF2	$f(x_1, x_2, x_3, x_4)$	0.9957	Model Rejected

1. Niger-Cat Model

$$\boldsymbol{y = 30.007 - 4.633x_1 + 4.475 \times 10^{-2}x_2 + 2.488 \times 10^{-2}x_3 + 1.1 \times 10^{-1}x_4 + 26.229x_5 + 4.425x_6 + 7.916 \times 10^{-2}x_7 + 3.893 \times 10^{-1}x_8 + 1.103x_9 + 8.067x_{10} + 33.726x_{11}}$$

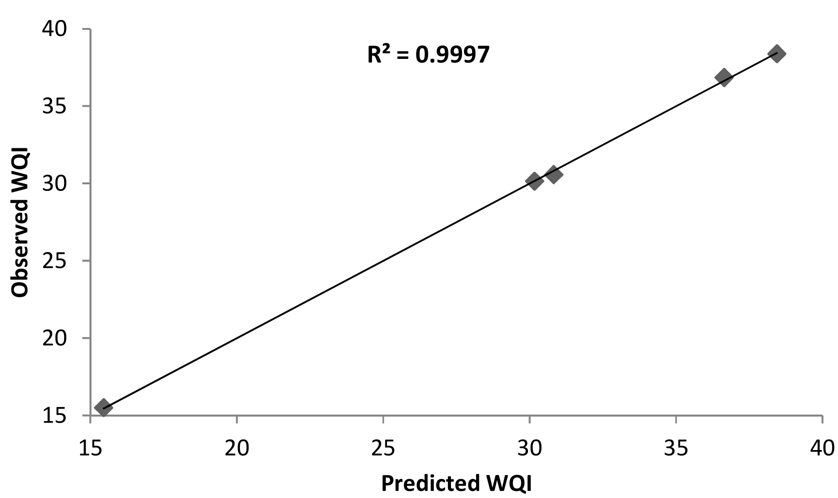


where y = Water Quality Index, x_1 = pH, x_2 = Total Dissolved Solids, x_3 = Conductivity, x_4 = Hardness, x_5 = Nitrate, x_6 = Sulphate, x_7 = Chloride, x_8 = Magnesium, x_9 = Sodium, x_{10} = Zinc, and x_{11} = Iron

Fig. 8. Predicted water quality index against the observed around Niger-Cat dump site

2. Don-Parkar Model

$$\boldsymbol{y = -24.489 - 2.114 \times 10^{-1}x_1 - 7.509 \times 10^{-2}x_2 - 3.844 \times 10^{-1}x_3 + 67.182x_4 + 15.158x_5 - 8.403 \times 10^{-1}x_6 + 5.792x_7 + 324.6x_8 + 115.203x_9}$$

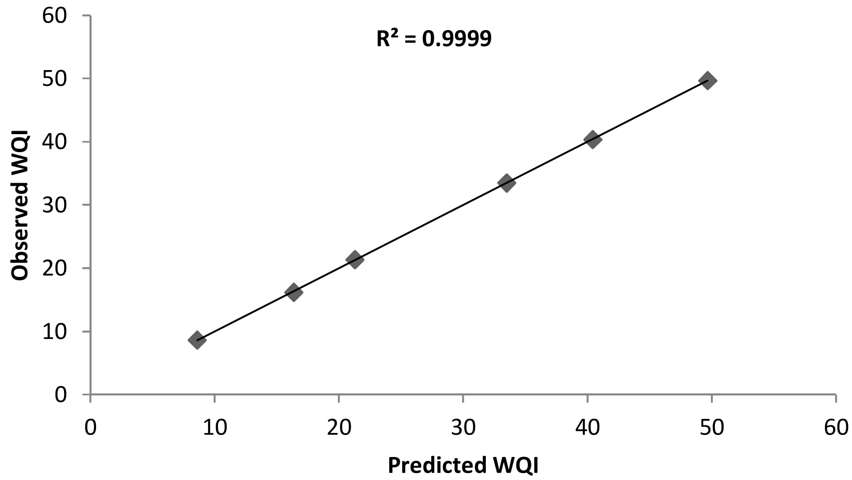


where y = Water Quality Index, x_1 = Total Dissolved Solids, x_2 = Conductivity, x_3 = Hardness, x_4 = Nitrate, x_5 = Sulphate, x_6 = Chloride, x_7 = Magnesium, x_8 = Zinc and x_9 = Iron

Fig. 9. Predicted water quality index against the observed around Don-Parkar dump site

3. Orhuwhorun Model

$$y = -24.489 - 2.114 \times 10^{-1}x_1 - 7.509 \times 10^{-2}x_2 - 3.844 \times 10^{-1}x_3 + 67.182x_4 + 15.158x_5 - 8.403 \times 10^{-1}x_6 + 5.792x_7 + 324.6x_8 + 115.203x_9$$



where y = Water Quality Index, x_1= Total Dissolved Solids, x_2 = Conductivity, x_3 = Hardness, x_4 = Nitrate, x_5 = Sulphate, x_6 = Chloride, x_7 = Magnesium, x_8 = Zinc and x_9 = Iron

Fig. 10. Predicted water quality index against the observed around Orhuwhorun dump site

3.2 Discussion

3.2.1 Water quality index of sampled boreholes, dug-wells and stream

The water quality of existing boreholes, dug-wells and stream around Niger-Cat, Don-Parkar and Orhuwhorun dump sites were examined using the Weighted Arithmetic Water Quality Index method [21,26-29]. The water quality results for the various water sources around the three dump sites are as presentedin Table 5.

3.2.1.1 Niger-cat dump site

Six (6) wells (3 boreholes and 3 hand dug-wells) were monitored during the sampling period of September, November and January to determine the water quality of these wells. The pH of the different sampled water around the dump ranged from 4.76 – 6.80 (see Table A2).According to Thakor [28], pH is one of most important water quality indicators. The pH of BH1, BH2, BH3 and DW3 were found below World Health Organization (WHO) standard limit (6.5 - 8.5) except for DW1 and DW2, indicating that water is acidic (see Table A1). BH3 and DW3 indicated higher acidity. TDS was within permissible limit except for DW1. Electrical Conductivity was above permissible limit at BH1 and DW1. Magnesium and Iron were relatively above standard limit at DW1. According to Deepika and Singh [30], water with high magnesium hardness especially the one related with sulphate ion has laxative effect on persons not accustomed to it. The water quality indices of sampled wells (BH1, BH2, BH3, DW1, DW2 and DW3) around dump site ranged from 8.20 – 208.18. The WQI obtained for BH1 and DW3 indicated poor quality water, this is in line with a similar work by Chaterjee and Raziuddin [21], while BH2 is of excellent quality. BH3 and DW2 have good water quality, while that of DW1 is not suitable for drinking. The unsuitability of water from DW1 for drinking is simply a function of its distance and depth (63 and 7m) and its vulnerability to ponding of runoff water due to topography (field observation confirmed it as of low elevation). In contrast, WQI for BH2 is rated excellent and could be justified by distance of 76m and depth of 15.8 m, respectively. Apparently, distance of water source to dump site and its depth impacted on WQI.

3.2.1.2 Don-Parkar dump site

Three (3) boreholes and 2 dug-wells were monitored for September, November and January for their water quality. Parameters such as TDS, Electrical conductivity, hardness, nitrate, sulphate and chloride were within permissible limit. pH at boreholes and dug-wells were below limit. pH ranged from 5.11 – 6.31 (see Table A3), indicating groundwater of sampled boreholes and dug-wells around Don-Parkar were slightly acidic. The WQI values for Don-Parkar varied from 15.52 – 38.40 as at the time of study. BH2, BH3, DW1 and DW2 have WQI values of 30.59, 36.86, 30.16 and 38.40, respectively; indicating water is of similar quality (i.e. very good quality water). The WQI value of BH1 was 15.52 indicating water is of excellent quality.

3.2.1.3 Orhuwhorun dump site

Water from 2 boreholes, 3 dug-wells and a stream were monitored for their water quality. Water around the dump was found to be slightly acidic as pH was below the WHO standard limit except for DW1 with pH value of 6.61 (see Table A4). Higher conductivity value was found in DW1 but was still within the permissible limit. DW1 and DW2 accounted for high chloride when compared with BH1, BH2, DW3 and SM1. However, chloride was within standard. Other parameters such as TDS, hardness, sodium, zinc and iron were in low concentrations which were within the specified standards. The WQI values were 16.37, 21.29 and 8.59 for BH1, DW3 and SM1, respectively; indicating water is of excellent quality. BH1 value was 33.50; DW1 was 49.66, while DW2 was 40.42. Thus, BH1, DW1 and DW2 water were within the range of good water quality.

The implication therefore, is that, at Niger-cat the activities on the dump site has started impacting on the environment and such water is not totally safe for human consumption especially BH1 and DW3, while DW1 is totally unsafe for drinking and it is capable of causing water-related diseases to human when consumed. For Don-Parkar and Orhuwhorun dump sites, activities on the dump sites have no significant impact on the water which is currently safe and causes no potential health risk to people when consumed especially BH1.

3.2.2 Comparative analysis of WQI at the three dump sites

Given the distribution of water quality Index (WQI) values and the corresponding rating for three dump sites in Table 5, the Orhuwhorun dump site with 6 water sources scored a total of 27 points, followed by Don-Parkar with 5 water sources scored 21 and Niger-Cat with 6 water sources scored 20 points, respectively. Apparently, Orhuwhorun dump site has the best water quality and this is explained by the fact that the boreholes and dug-wells are further apart from the dump site as compared with those of Niger-Cat and Don-Parkar.

3.2.3 Extracted factor by principal component analysis

From the principal component analysis results (see Tables 6 – 11), the number of significant factor components was determined based on scree plots (see Figs. A1 – A3) and eigenvalue criterion (see Tables 6, 8 and 10) for Niger-Cat, Don-Parkar and Orhuwhorun, respectively.

At Niger-Cat, five (5) Principal Factors (F1 – F5) were extracted explaining 100% cumulative variations in the water quality data set (see Table 6). Factors 3, 4 and 5 had eigenvalues < 1. According to Lei [31], Factors with eigenvalues < 1 were regarded as insignificant. At Don-Parkar, four (4) Principal Factors (F1 – F4) were extracted explaining 100% cumulative variations in the water quality data set (see Table 8). F1 and F2 with eigenvalues > 1, while Factors 3 and 4 had eigenvalues < 1 explaining 6.8% of total variation of the data set. For Orhuwhorun, five (5) Principal Factors (F1 – F5) were extracted explaining 100% of total variation in the data set (see Table 10). Factors 1 and 2 had eigenvalues > 1 and were regarded as significant. Varimax rotation was performed on significant extracted factors (F1 and F2) to optimize the result of PCA. Of high significant for the rotated components are the values of the correlated coefficient in bold prints (see Tables 7, 9 and 11), which explained parameters to be selected for the development of models. Variables clustered together around the axes indicate component factor values with the highest correlation coefficient (see Figs. 5 - 7). The Varimax rotated factors, VF1 accounted for 81.49% and VF2 accounted for 11.01% of the total variation for Niger-Cat (see Fig. 5), for Don-Parkar, VF1 and VF2 accounted for 72.97 and 20.20% of total variation, respectively (see Fig. 6) and for Orhuwhorun, VF1 and VF2 accounted for 53.60 and 39.62% of total variation, respectively (see Fig. 7). After Varimax rotation, from the twelve (12) water quality input parameters from the three dump sites, for Niger-Cat, eleven (11) important parameters for F1 and one (1) for F2 were extracted for model development, for Don-Parkar, nine (9) and three (3) for F1 and F2 and eight (8) and four (4) selected parameters for F1 and F2, respectively for Orhuwhorun. A multiple linear regression simulation using XLSTAT 2016 version-6 was run for Factors 1 and 2 against each dump site. The best models were selected based on goodness of fit, (R^2) value for Niger-Cat, Don-Parkar and Orhuwhorun dump sites (see Figs. 8 – 10).

3.2.4 Comparing predicted WQI against observed

Figs. 8 - 10 present a graphical illustration of modeled WQI values compared with the observed WQI values (see also, Figs. A4 – A6). At Niger-Cat, the modeled WQI for Boreholes: BH1, BH2 and BH3 were 60.936, 8.091 and 40.639 while the observed were 60.911, 8.195 and 41.749, respectively (see Fig. 8). The modeled WQI value for BH1 was slightly higher than observed value with residual value of -0.025. For BH2, modeled WQI value was lower with residual of 0.1044, while for BH3, the residual was 1.1098. For Dug-wells: DW1, DW2 and DW3, the modeled values were 208.072, 49.726 and 52.004 while the observed values were 208.180, 49.296 and 51.537 with residuals of 0.1076, -0.4304 and -0.4665, respectively.

At Don-Parkar, the modeled WQI values for Boreholes: BH1, BH2 and BH3 were 15.454, 30.819 and 36.637 while the observed values were 15.518, 30.586 and 36.859 (see Fig. 9) with residual values 0.0623, -0.2328 and 0.2229, respectively. For dug-wells: DW1 and DW2, the modeled values were 30.165 and 38.441 while observed values were 30.158 and 38.395 with residuals of -0.0071 and -0.4406.

At Orhuwhorun, the modeled WQI values for BH1 and BH2 were 33.514 and 16.211 while the observed values were 33.497 and 16.366 (see Fig. 10), with residuals of -0.0167 and 0.1551 respectively. For DW1, DW2 and DW3 the modeled values were 49.690, 40.372 and 21.372 while the observed were 49.663, 40.418 and 21.287 with residuals of -0.0271, 0.0454 and -0.0854. For Stream SM1, the modeled value was 8.6634 while the observed value was 8.593 with residual of -0.0713.

4. CONCLUSION

This work had shown that the predicted WQI values compared well with the observed WQI values. Therefore, the developed models can be used to predict and monitoring the water quality index of sampled boreholes, dug-wells and stream around Niger-Cat, Don-Parkar and Orhuwhorun dump sites. Also, it was observed from the water quality index that some wells at Niger-Cat dump were of poor quality and not safe for consumption. For Don-Parkar and Orhuwhorun, the WQI indicated that water around the dump sites is currently safe.

5. RECOMMENDATION

This study had revealed that the activities of the dump sites is affecting the water sources around the dump sites especially Niger-Cat dump site. It also revealed that the water around the dump sites is acidic. Therefore, it is recommended that the water at Niger-Cat, Don-Parkar and Orhuwhorun dump sites should be treated before consumption.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX A

Table A1. Drinking water standards, recommended by WHO and Unit Weight

S/N	Parameters	Standards	Unit Weight, W_i
1	pH	6.5 – 8.5	0.0291
2	TDS	500	0.0005
3	Conductivity	200	0.0012
4	Turbidity	5	0.0494
5	T. Hardness	200	0.0012
6	Nitrate	50	0.0049
7	Sulphate	250	0.0010
8	Chloride	250	0.0010
9	Magnesium	50	0.0049
10	Sodium	200	0.0012
11	Zinc	3	0.0823
12	Iron	0.3	0.8232

Table A2. Water quality index around Niger-Cat dump site

Parameters	BH1	BH2	BH3	DW1	DW2	DW3
pH	5.08	5.57	4.76	6.81	6.80	3.98
TDS	143.70	8.33	78.67	513.70	105.00	94.67
Conductivity	258.70	15.67	142.07	924.30	188.90	170.10
Turbidity	1.04	1.02	1.95	1.37	2.87	2.73
T. Hardness	72.77	3.64	24.57	128.50	39.43	34.70
Nitrate	0.28	0.01	0.17	0.61	0.32	0.20
Sulphate	1.27	0.14	2.10	5.71	3.53	2.63
Chloride	82.09	3.15	20.45	220.40	34.94	29.89
Magnesium	7.84	0.37	1.84	53.73	4.15	3.14
Sodium	2.01	0.12	1.06	20.31	1.66	1.24
Zinc	0.25	0.10	0.16	2.85	0.21	0.19
Iron	0.20	0.02	0.13	0.72	0.17	0.15
ΣW_iQ_i	**60.91**	**8.20**	**41.75**	**208.18**	**49.30**	**51.54**
ΣW_i	**1**	**-**	**-**	**-**	**-**	**-**
WQI	**60.91**	**8.20**	**41.75**	**208.18**	**49.30**	**51.54**

Table A3. Water quality index around Don-Parkar dump site

Parameters	BH1	BH2	BH3	DW1	DW2
pH	5.65	5.43	5.73	5.11	6.31
TDS	13.33	17.33	26.00	20.67	51.00
Conductivity	23.67	31.33	46.33	38.33	92.00
Turbidity	0.96	0.61	1.12	3.26	1.25
T. Hardness	5.53	8.98	12.04	9.80	24.17
Nitrate	0.01	0.02	0.04	0.04	0.10
Sulphate	0.33	0.58	0.62	0.56	0.90
Chloride	5.40	7.52	11.11	7.84	17.13
Magnesium	0.69	1.30	2.23	1.71	3.45
Sodium	1.20	0.96	1.18	0.92	1.45
Zinc	0.11	0.13	0.14	0.13	0.15
Iron	0.04	0.10	0.12	0.08	0.13
ΣW_iQ_i	**15.52**	**30.59**	**36.86**	**30.16**	**38.40**
ΣW_i	**1**	**-**	**-**	**-**	**-**
WQI	**15.52**	**30.59**	**36.86**	**30.16**	**38.40**

Table A4. Water quality index around Orhuwhorun dump site

Parameters	BH 1	BH2	DW1	DW2	DW3	SM1
pH	6.15	5.63	6.61	6.07	5.06	6.16
TDS	23.00	12.33	87.67	67.00	27.33	9.67
Conductivity	41.00	22.33	157.67	120.90	49.27	17.33
Turbidity	1.69	2.06	4.18	3.00	2.12	1.48
T. Hardness	11.45	5.92	34.15	23.33	7.08	4.25
Nitrate	0.04	0.01	0.11	0.10	0.01	0.01
Sulphate	0.64	0.30	1.02	1.72	0.83	0.18
Chloride	9.93	5.29	28.66	19.73	6.09	3.25
Magnesium	2.10	0.62	5.86	1.36	0.66	0.49
Sodium	1.12	0.19	1.72	0.98	0.46	0.13
Zinc	0.14	0.11	0.20	0.16	0.08	0.10
Iron	0.11	0.04	0.16	0.13	0.06	0.02
$\Sigma W_i Q_i$	**33.50**	**16.37**	**49.66**	**40.418**	**21.29**	**8.59**
ΣW_i	**1**	**-**	**-**	**-**	**-**	**-**
WQI	**33.50**	**16.37**	**49.66**	**40.418**	**21.29**	**8.59**

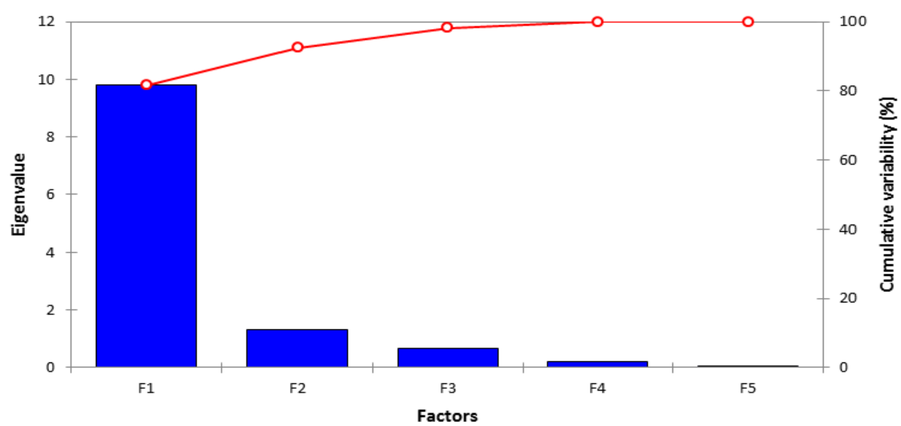

Fig. A1. Scree plot for factor extraction among water quality parameters at Niger-Cat

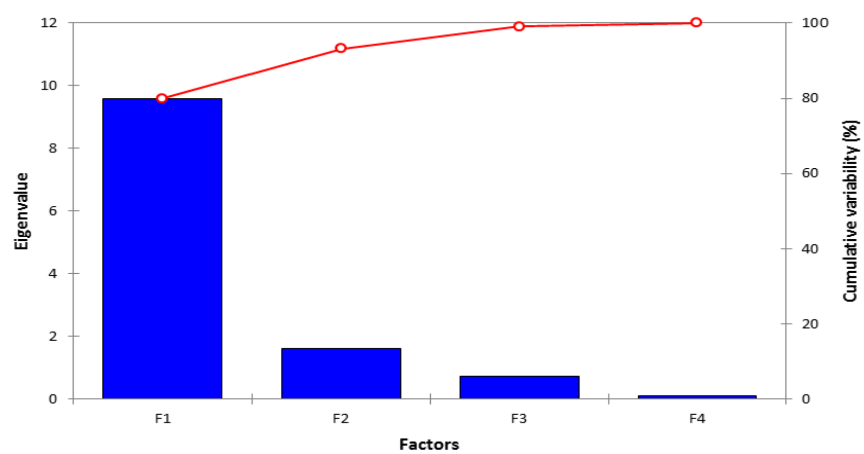

Fig. A2. Scree plot for factor extraction among water quality parameters at Don-Parkar

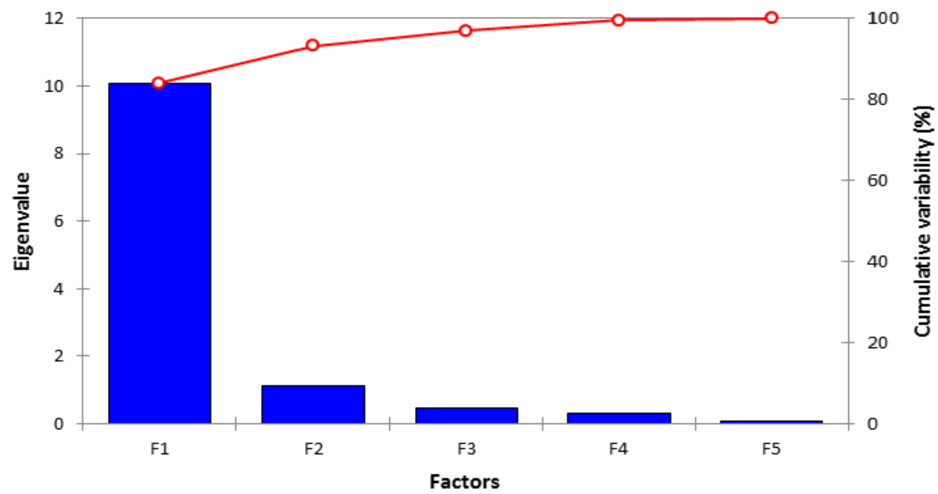

Fig. A3. Scree plot for factor extraction among water quality parameters at Orhuwhorun

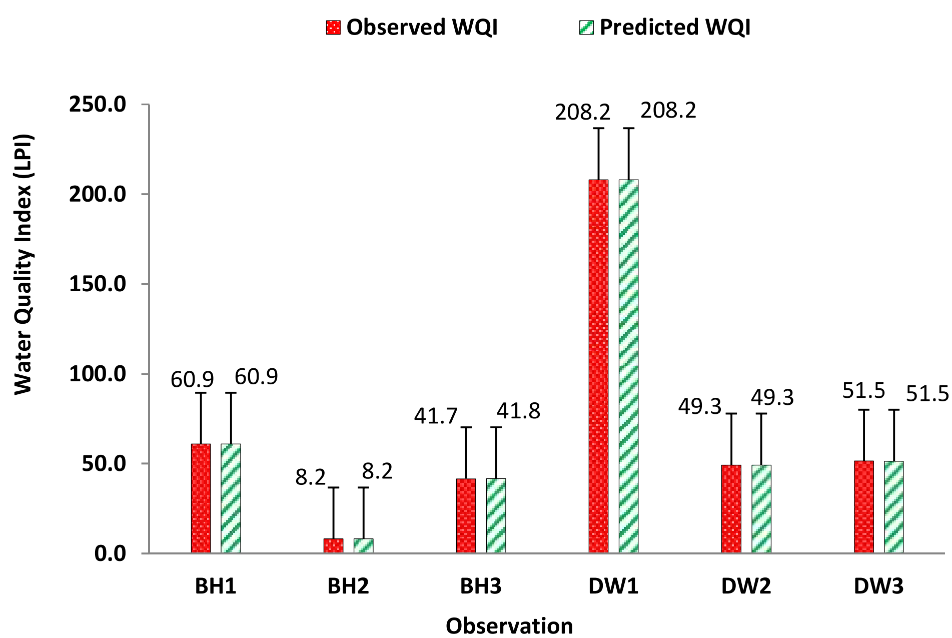

Fig. A4. Observed against Modeled Leachate Pollution Index Values around Niger-Cat dump site

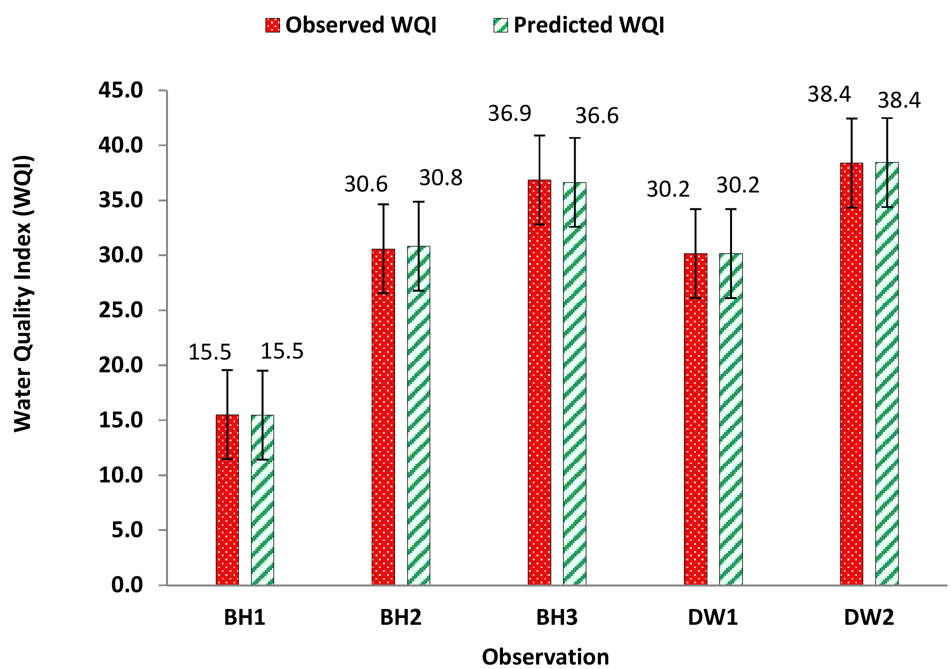

Fig. A5. Observed against Modeled Leachate Pollution Index Values around Don-Parkar dump site

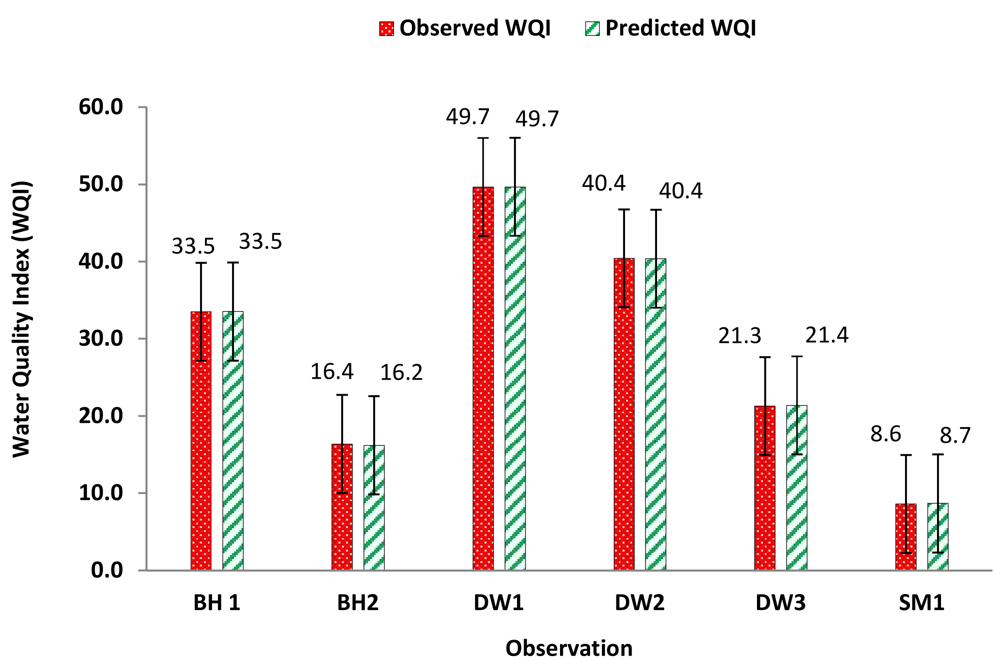

Fig. A6. Observed against Modeled Leachate Pollution Index Values around Orhuwhorun dump site

Table A5. Description of water samples location around the three dump sites

Dump Site	Latitude (N)	Longitude (E)	Distance from edge of dump (m)	Surface to water table (m)	Depth of well (m)
NIGER-CAT (NC)					
BH1	5° 34' 26.84"	5° 44' 51.46"	64.5	1.1	14.8
BH2	5° 34' 35.20"	5° 44' 58.90"	76	1.5	15.8
BH3	5° 34' 22.98"	5° 44' 55.23"	102.3	1.3	17
DW1	5° 34' 31.50"	5° 44' 58.20"	63	1.2	7
DW2	5° 34' 38.10"	5° 44' 56.40"	40.6	0.9	5.9
DW3	5° 34' 34.32"	5° 44' 50.76"	36	1.4	7.2
DON-PARKAR (DP)					
BH1	5° 40' 36.34"	5° 45' 17.54"	414.5	1.8	15.2
BH2	5° 40' 44.34"	5° 45' 15.78"	139.4	1.5	16.3
BH3	5° 40' 53.46"	5° 45' 19.15"	44.5	1.7	16.9
DW1	5° 40' 38.58"	5° 45' 12.54"	340	1.4	5.6
DW2	5° 40' 40.32"	5° 45' 15.72"	262	0.9	4.8
ORHUWHORUN (ORH)					
BH1	5° 30' 51.66"	5° 50' 56.59"	244.84	4.9	18
BH2	5° 30' 47.90"	5° 50' 44.01"	265.9	4.5	16.8
DW1	5° 31' 07.08"	5° 50' 49.62"	350	5.9	8.2
DW2	5° 31' 00.58"	5° 50' 57.86"	100	2.5	6.2
DW3	5° 30' 53.06"	5° 50' 49.58"	158	2.5	5.4
SM1	5° 30' 51.30"	5° 50' 45.54"	125	-	2.1

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