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Prediction of Hydrogeologic Risks of Dump Sites using Fuzzy Approach A Case Study of Some Dumpsites at Igbara-Oke, South-Western Nigeria

Bosede O. Ayeni, Gregory O. Omosuyi, John C. Nwaiwu, Adetayo A. Adebayo

Abstract: Geophysical investigation was carried out within the vicinity of some open active waste dumpsites at Igbara-Oke, Southwestern Nigeria along ten traverses with sixty-two (62) Vertical Electrical Sounding (VES) positions being occupied in the East- West and South- North direction to assess the geology and hydrogeologic condition of the subsurface around the dumpsites. The interpreted geoelectric sections showed subsurface layers as top soil with resistivity range of 5- 448 Ωm and thickness 0.30 -7.7m; weathered layer resistivity value varying from 9-250 Ωm had thickness values between 0.4m –7.1m. Thickness of the fractured/fault layer having resistivity values lesser but not greater than 750 Ωm, ranges from 1.2 m to 11m and depth to bedrock thickness extended beyond 17.9m having resistivity value exceeding 1000Ωm. Underlying possible lithological characteristics was inferred using the information from the geoelectric sections. Aquifer systems of weathered/fractured unconfined aquifer, weathered/fractured confined aquifer, weathered layer aquifer, weathered layer/fractured semi-confined aquifer types were delineated. A fuzzy model implemented asserts the relative hazard rating of the dumpsites as 1.72 and 1.67 on a scale of 10, indicating the dumpsites may not be currently posing a risk based on its sizes, waste content and localization of leachates plume.

Keywords: Groundwater, Hydrogeologic, Hydrogeological risks, Fuzzy logic, Relative Hazard Rating

I. INTRODUCTION

In recent times, the problem of environmental pollution and poor waste management is much more acute becoming a source of concern to researchers and scientists from all related field. The unmanaged handling and dumping of solid wastes has resulted in contamination which has contributed to the current deteriorating quality of groundwater (Mohammed, 2006). Groundwater, being one of the earth's most important resources for human life is polluted artificially or geologically through induced degradation of its natural quality. Its quality depends upon the geological environment, human activity, natural movement, recovery and utilization (Reynolds, 1997, Ogunribido, 2011, Jegede *et al*, 2011, Bayowa *et al*, 2014). Pollutants create contaminant plume within an aquifer, its advancing boundary often called a plume edge, can intersect with groundwater wells, making the water supplies unsafe for humans and wildlife (Offodile, 2002, Jacques, 2009, Bayode, 2011, Awoniyi, 2013, Brian 2016).

Geophysics is non-invasive method of monitoring contamination of water and soil from leachates and soil in waste disposal sites (Umar et al, 2004, Shemang *et al*, 2006, Fajana, 2013, Susaiappan *et al*, 2015). Hence, this study seeks to predict the impact of the dumpsites on the hydrogeologic structures within the study area through the use of Geophysical methods and Fuzzy prediction methodology.

II. DESCRIPTION OF THE STUDY AREA

The area of study is within the headquarters of Ifedore local government of Ondo State. It lies between latitudes 810000 – 820000 and Longitudes 726600- 727800 of the Universal Traverse Mercator covering approximately 12090 sqmeter (Fig 1). The dumpsites are openly operated within residential buildings and still opening up for more settlement. The study area occupies about 0.01209 sqkm and topographically, it is characterized by gentle relief with elevation range of 347m – 367m (Fig. 2).

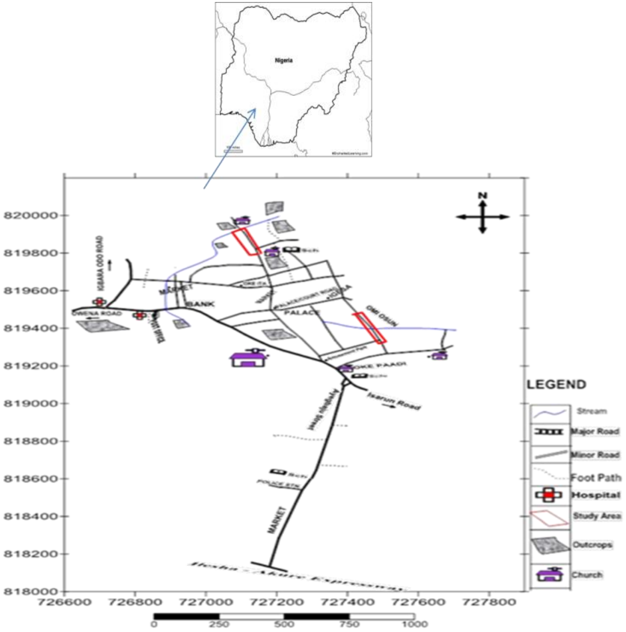

Fig. 1: Map of the Study Area

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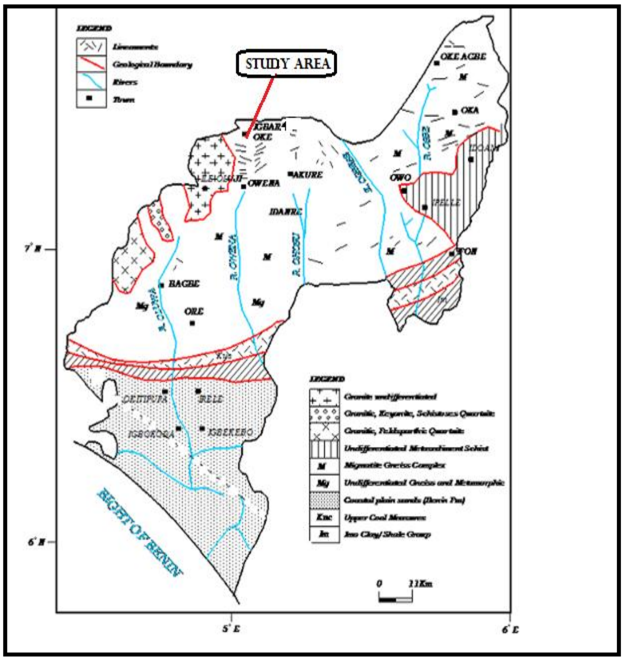

Fig. 2: Geologic Map of Ondo State showing the Study Area

A. Geology and Hydrogeology of Study Area

Igbara-Oke is underlain by the Precambrian rocks of the Basement Complex of Southwestern Nigeria (Fig 2). The main lithologies of the southwestern (SW) Nigeria basement complex include the amphibolites, migmatite gneisses, granites and pegmatites. The study area is underlain by the Migmatite Gneiss with granitic intrusions been observed in most places (Rahaman, 1976, 1988, Obaje 2009). The major surface water in the study area are rivers and bear the same characteristics as most Nigeria rivers in that they are seasonal – volume reduces drastically in the dry season, while some such river overflow their banks in the rainy season. However, the area is drained by streams being tributaries of River Owena which is of dendritic pattern and they flow in the South West – North East direction. The streams seem to be structurally controlled due to the occurrence of outcrop along the stream channel observed in the dry season.

III. PROPOSED METHODOLOGY

A. Data Acquisition and Processing

Geophysical survey was carried out along outline traverses around the dumpsites. Ten (10) traverses were established running approximately E-W across the dumpsites, and S-N extending from 60m-240m respectively. Same traverses were occupied for Vertical Electrical sounding carried out at 20m station spacing using half Schlumberger configuration AB/2 of 40m. The Vertical Electrical sounding data were manually interpreted using the conventional curve matching approach, and further computer forward modeling program (Window Resist Version 1.0) was used to smoothen the primary geoelectric parameters derived from the manual interpretation.

Thickness of the vadose zone and aquifer thickness derived from the interpretation were combined with other parameters in a multiplicative-addictive algorithm and Gaussian membership function (MF) were used to fuzzify the input and output variables in MATLAB environment for modeling the hazard rating of the dumpsite.

B. Fuzzy Methodology

The theory of fuzzy sets broadens the concept of crisp set, thus allowing objects to partially belong to a set. If ‘x’ is a significant member of fuzzy set ‘S’, it does not mean that the proposition is true or false, but it may be true only to some degree, the degree to which ‘x’ is really a member of ‘S’. For a space of objects, ‘x’, represented by ‘U’, a fuzzy set ‘S’ can be defined by this pair; $S = \{(x, \mu_S(x))\ x \in U, \mu_S(x): U \rightarrow [0, 1]$**.** The universe of discourse is represented by the space U and the function $\mu_S(x)$ is called the membership function. The fuzzy set ‘S’ defined above by the set of pairs is known as ‘fuzzy relation’ when the element ‘x’ is formed by a tuple of objects. Fuzzy relations are the natural generalization of crisp relations to the theory of fuzzy sets. Three classes of operations (t-norm functions, s-norm functions and average operation) are performed on fuzzy sets. Fuzzy models are maps between input and output spaces described using conditional propositions and inference operation. Major characteristics of fuzzy models include representation independent variables of using fuzzy labels; Reduction of commitment through fuzzy outputs; Better use of knowledge and data and Model Interpretability (Pedrycz et al, 1999).Of all advantages of fuzzy logic, the most significant lies in its simplicity and intuitiveness.

C. Relative Hazard rating Prediction Fuzzy based model

The relative hazard rating prediction fuzzy based model is composed of three main modules. The fuzzy model structure for the relative hazard rating is mainly governed by,

$$RHR = f(SHA, PHA, RHA) \tag{1}$$

In more explicit terms, equation (1) could be further expressed in equations (2 – 13) respectively.

$$RHR = \{(SHA, \mu_{sha}(SHA)), (PHA, \mu_{pha}(PHA)), (RHA, \mu_{rha}(RHA))\} \tag{2}$$

where RHR = fuzzified Relative Hazard Rating output; f = *fuzzy* membership function (Gaussian membership function was used); SHA = Source Hazard Assessment input variable; PHA = Pathway Hazard Assessment input variable; RHA = Receptor Hazard Assessment input variable; $\mu_{sha}, \mu_{pha}, \mu_{rha}$ = membership functions of the fuzzy sets input attributes for source, pathway and receptor hazards

The Source hazard Assessment fuzzification is expressed as

$$SHA = \{(RLF, \mu_{rlf}(RLF)), (RLS, \mu_{rls}(RLS))\} \tag{3}$$

$$RLF = \{(PPt, \mu_{ppr}(PPR)), (LFA, \mu_{lfa}(LFA)), (LFC, \mu_{lfc}(LFC))\} \tag{4}$$

$$PPR = \{(PPT, \mu_{ppt}(PPT))\} \tag{5}$$

$$LFA = \{(WFA, \mu_{wfa}(WFA))\} \tag{6}$$

$$LFC = \{(Zcs, \mu_{zcs}(Zcs)), (Zsl, \mu_{zsl}(Zsl)), (Zct, \mu_{zct}(Zct)), (Zck, \mu_{zck}(Zck)), (Zgt, \mu_{zgt}(Zgt))\} \tag{7}$$

$$RLS = \{(HI, \mu_{hi}(HI)), (B, \mu_b(B)), (C, \mu_c(C)), (D, \mu_d(D))\} \tag{8}$$

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$$PHA=\{(CTR,\mu_{ctr}(CTR)),(AQR,\mu_{aqr}(AQR))\} \qquad (9)$$

$$CTR=\{(Ztl,\mu_{ztl}(ZTL)),(Zkl,\mu_{zkl}(Zkl)),(Zgl,\mu_{zgl}(Zgl))\} \qquad (10)$$

$$AQR=\{(Zat,\mu_{zat}(Zat)),(Zap,\mu_{zap}(Zap)),(Zgg,\mu_{zgg}(Zgg)),(Zdw,\mu_{zdw}(Zdw))\} \qquad (11)$$

The Receptor Hazard Assessment fuzzification is shown as

$$RHA=\{(HPO,\mu_{hpo}(HPO)),(CAG,\mu_{cag}(CAG)),(LVS,\mu_{lvs}(LVS))\} \qquad (12)$$

Gaussian membership function used for the mapping of the input and output variables is given by,

$$f_{gaus}(LV_i;\sigma_j,c_j)=e^{\frac{-(LV_i-c_j)^2}{2\sigma_j^2}} \qquad i=1,\ldots,n j=1,\ldots,m \qquad (13)$$

$$f_{gaus}(LV_i;\sigma_j,c_j)=\begin{cases}\ell^{\frac{-(LV_i-c_1)^2}{2(\sigma_1)^2}}\\ \ell^{\frac{-(LV_i-c_2)^2}{2(\sigma_2)^2}}\\ \ell^{\frac{-(LV_i-c_3)^2}{2(\sigma_3)^2}}\end{cases} \qquad (14)$$

where f_{gaus} = Gaussian membership function; LV_i = linguistic variable of i-th variable; σ_j, c_j = determines the skewness and center of the curve for j-th linguistic variable; m and n = maximum number of linguistic variable and input variable respectively.

Data collected from historical data and field were put through quality checks and calculated using empirical formula as needed. The fuzzy model for determining the Relative Hazard Assessment Rating of dump sites is implemented in MATLAB 2015a using fuzzy toolbox. The groundwater hazard rating flow procedure is shown in Fig. 3. Ground water rating parameters are calculated using the empirical formula proposed by Raj *et al*, (2007) using parameters in Table 1.

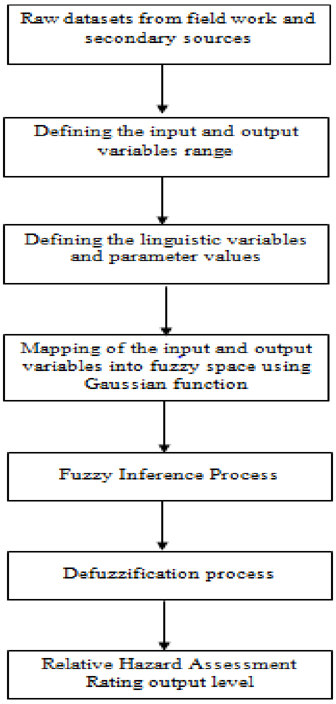

Fig. 3: Groundwater Hazard Rating Flow Diagram

Table 1: Groundwater Hazard Rating Input Parameters

S/No	Component Type	Parameters
1.	Source Hazard	A .i. Precipitation ii. Land Area iii. Cover Slope (CS) iv. Soil Thickness (ST) v. Clay Thickness (CT) vi. Clay Permeability(CK) B. Leachate Strength (S_L)

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2.	Pathway Hazard	A. Containment Structure i. Clay Liner Thickness (CLT) ii. Clay Liner Permeability (CLK) iii. Geo-membrane Thickness (GT) B. i. Aquifer thickness (AT) ii. Aquifer Permeability (AK) iii. Groundwater Gradient (H) iv. Distance to Well
3.	Receptor Rating	Ground water Existence Population Crop Livestock

The definition of the input and output variable(s) range is described in Table 2.

Table 2: Defining the Input and Output Variables Range

S/N	Input variable	Parameters	Low (L)	Average (A)	High (H)
1	PPT	Precipitation (cm)	0 – 20	20–100	100–200
2	WFA	Waste Fill Area (ha)	0 – 5	5 – 25	25– 100
3	PPR	Precipitation rating	1 – 4.472	4.472 – 10	10– 14.14
4	LFA	Land Fill Area rating	2 – 4.472	4.472 – 10	10– 20
5	Zcs	Cover Slope in percentage	5 – 100	1 – 5	0 – 1
6	Zsl	Soil layer thickness (cm)	45 – 200	1 – 45	0 – 1
7	Zct	Clay layer thickness (cm)	60 – 500	1 – 60	0 – 1
8	Zck	Clay layer permeability (cm/sec)	$0 – 10^{-7}$	$10^{-7} – 10^{-5}$	$10^{-5}– 1$
9	Zgt	Geo-membrane thickness (mm)	1.5 – 2	1 – 1.5	0 – 1
10	LFC	Land Fill Cover rating	0 – 2	2 – 4	4 – 6
11	RLF	Relative leachate flow	0 – 100	100– 400	400– 1000
12	HI	Presence of Hazardous waste Industries in the vicinity with no HW landfill	0	-	1
13	B	Biodegradable waste percentage	1 – 20	20 – 65	65– 100
14	C	C&D waste percentage	65 – 100	20 – 65	1 – 20
15	D	Waste fill height/depth	1 – 5	5 – 15	15– 30
16	RLS	Relative Leachate Strength	1 – 70	70 – 140	140– 210
17	SHA	Source Hazard Assessment rating	1000 – 40000	40000 – 80000	80000 – 130000
18	Ztl	Clay Liner thickness (cm)	90 – 200	1 – 90	0 – 1
19	Zkl	Clay Liner Permeability (cm/sec)	$0 – 10^{-7}$	$10^{-7} – 10^{-5}$	$10^{-5}– 1$
20	Zgl	Geo-membrane thickness (mm)	2.5 – 5	1 – 2.5	0 – 1
21	CTR	Containment rating	0 – 1	1 – 1.5	1.5 – 2
22	Zat	Aquifer thickness (m)	50 – 100	5 – 50	0 – 50
23	Zap	Aquifer Permeability (cm/sec)	$10^{-8} – 10^{-4}$	$10^{-4} – 10^{-2}$	$10^{-2} – 1$
24	Zgg	Groundwater gradient in percentage	0 – 1	1 – 5	5 – 100
25	Zdw	Distance to groundwater well (m)	3000 – 5000	500 – 3000	0 – 500

26	AQR	Aquifer Zone Rating	0 – 1	1 – 2	2 – 3
27	PHA	Pathway Hazard Assessment rating	0 – 1.5	1.5 – 3	3 – 5
28	HPO	Human Population Presence	0	-	0.5
29	CAG	Crops Area Using groundwater	0	-	0.25
30	LVS	Livestock & Sensitive Environment presence	0	-	0.25
31	RHA	Receptor Hazard Assessment rating	0 – 0.3	0.3– 0.7	0.7- 1.0
32	RHR output	Relative Hazard Rating Output	1 – 4	4 – 7	7 – 10

Mapping of the input and output variables into fuzzy space using Gaussian function is the nest stage. The Gaussian membership function (MF) is used to fuzzify the input and output variables in equations 13.Fuzzification with Gaussian membership function (MF) is shown in equations 14 with parameter values for σ_j, c_j .

Table 3: Defining the Range of Linguistic Variables and Parameter Values

S/N	Input variables	Description	Low (σ_1, c_1)	Average (σ_2, c_2)	High (σ_3, c_3)
1	PPT	Precipitation (cm)	10,2	20,60	46,190
2	WFA	Waste Fill Area (ha)	3,0.4	4,15	30,95
3	PPR	Precipitation rating	1.7,1	1.3,7.3	2.1,14.2
4	LFA	Land Fill Area rating	1.1,2.1	1.4,7.3	4.5,19.5
5	Zcs	Cover Slope in percentage	35,90	1.5,3	2,0.5
6	Zsl	Soil layer thickness (cm)	60,190	9,25	2,1
7	Zct	Clay layer thickness (cm)	170,450	9,30	7,0.7
8	Zck	Clay layer permeability (cm/sec)	0.01,0	0.015,0.045	0.37,0.99
9	Zgt	Geo-membrane thickness (mm)	0.27,2.1	0.12,1.25	0.4458,0
10	LFC	Land Fill Cover rating	1,0	0.5,3	0.85,5.8
11	RLF	Relative leachate flow	50,0	70,250	250,970
12	HI	Presence of Hazardous waste Industries in the vicinity with no HW landfill	0.24,0	-	0.24,1
13	B	Biodegradable waste percentage	10,0.7	11,42	15,98
14	C	C&D waste percentage	15,98	11,42	10,0.7
15	D	Waste fill height/depth	2,1	2.5,10	6.6,29
16	RLS	Relative Leachate Strength	30,1	16,106	30,205
17	SHA	Source Hazard Assessment rating	200,001,000	1,000,060,000	24,000,130,000
18	Ztl	Clay Liner thickness (cm)	45,195	18,50	2,1
19	Zkl	Clay Liner Permeability (cm/sec)	0.01,0	0.01,0.03	0.35,0.95
20	Zgl	Geo-membrane thickness (mm)	1.1,4.8	0.4,1.75	0.5,0.05
21	CTR	Containment rating	0.45,0.1	0.13,1.25	0.22,1.98
22	Zat	Aquifer thickness (m)	21.23,97	9,30	2,0.5
23	Zap	Aquifer Permeability (cm/sec)	0.008,0	0.005,0.018	0.35,0.97
24	Zgg	Groundwater gradient in percentage	1,0	0.7,3.5	32,97

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25	Zdw	Distance to groundwater well (m)	9,004,900	6,001,800	250,0
26	AQR	Aquifer Zone Rating	0.45,0	0.23,1.5	0.45,2.98
27	PHA	Pathway Hazard Assessment rating	0.65,0.1	0.37,2.25	0.9,4.9
28	HPO	Human Population Presence	0.1,0	-	0.1,0.48
29	CAG	Crops Area Using groundwater	0.06,0	-	0.06,0.25
30	LVS	Livestock & Sensitive Environment presence	0.06,0	-	0.06,0.25
31	RHA	Receptor Hazard Assessment rating	0.15,0	0.1,0.5	0.15,1
32	RHR output	Relative Hazard Rating O utput	1.8,0	0.72,5.5	1.35,10

Fuzzy Inference Process is carried out after mapping of the variables into fuzzy space. Mamdami FIS fuzzy inference type was used in the inference process with the stage described in Fig. 3. The fuzzy inference process is described in Rule 1 in the expression below:

IF I_i is $x_{j I_i}$ AND,..., AND I_n is $x_{m In}$ THEN O is y_j (14)

where $x_{j I_i}$ = weights on the input universes; I_i = i-th input variable; I_i is $x_{j I_i}$,..., I_n is $x_{m I n}$ = fuzzy propositions defined on input space by the fuzzy sets I_i,...,I_n; y_n = weight on output universe (Relative Hazard Assessment output space); O = Output value of Relative Hazard Assessment rating.

Fig. 4 shows the architectural diagram of the fuzzy-based model

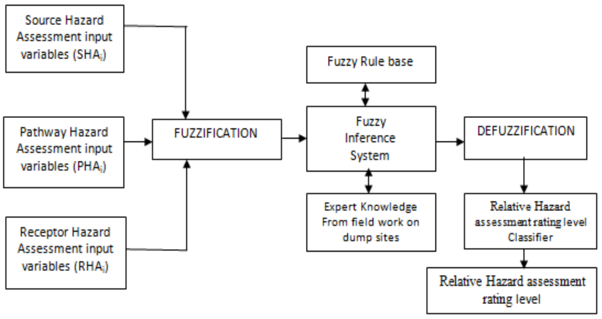

Fig. 4: Fuzzy Model for Relative Hazard Assessment Rating

IV. RESULT AND DISCUSSION

Geophysical investigation of the two old active dumpsites, revealed the subsurface configuration to consist of fractured zone, contacts and weathered/unconsolidated surficial material with thickness up to 5m. The mean annual rainfall, which is the major form of precipitation, is about 150cm. Total land area was 0.61968ha at CELE and 0.5897ha at OSUN. Cover slope of 10.8% was recorded at CELE and OSUN had a total of 4.2%. Both dumpsites are been operated as open sites, the thickness of installed clay barrier was 0cm due to absence of clay liner at the bottom of the dumpsites. Hence, permeability of clay liner was equally 0 cm/sec. At both CELE and OSUN dumpsites, there were no geomembrane available; therefore, parameter value was set at 0mm. About 98% of the waste content at the dumpsites are biodegradable material from domestic/ household waste and traces of construction and demolition materials. Hazardous materials such as radioactive waste types were absent at both sites. The geoelectric section showed the average thickness of the vadose zone at CELE dumpsite to be 0.159mm and 1.45mm at OSUN. Permeability of the vadose zone was calculated to be 0.168cm/sec and 0.175cm/sec respectively. Aquifer permeability in was 0.093 c,/sec at CELE and 0.126 cm/sec at Osun dumpsite. The groundwater gradient was 33% and 17.4% respectively; the nearest well to the dumpsites was 15m away at CELE and 5m at Osun site. The area around the waste dumpsites is currently being occupied by both human and livestock. However, irrigation or intensive agricultural practices does not exist. Sensitive environment is equally absent. These served as input parameters for the computation. The result of the rating is presented as positive integer on a scale of 0-10. (Fig. 4).

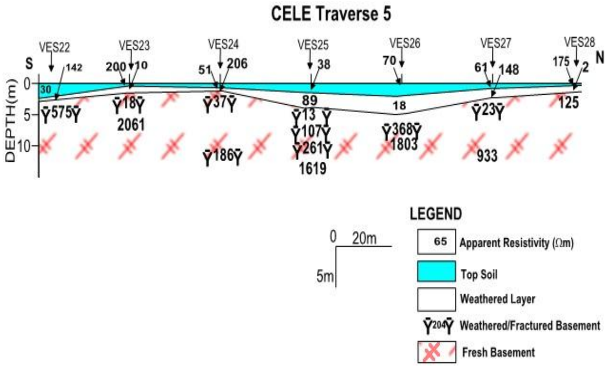

Fig.4: Geoelectric Section Along CELE Traverse 5

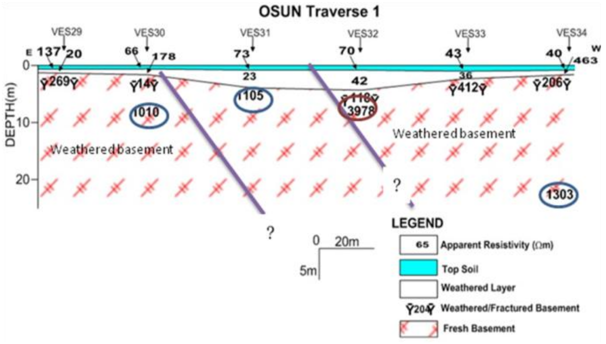

Fig.5: Geoelectric Section along Osun Traverse 1

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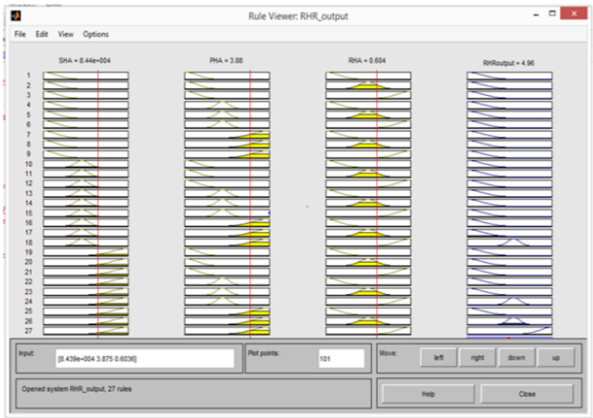
The same configuration was observed at OSUN site between station 20m and 60m where the same fractured zone trending in the East–West direction was delineated along the first two traverses, down slope towards the North, the weathered material became thicker as a result of deposition into the stream (Fig. 5).

The fuzzy model for determining the Relative Hazard Assessment Rating is implemented using Fuzzy Toolbox in MATLAB 2015a. A simulation using the parameter values gotten from the collected data from Igbara-Oke dumpsites was carried out. Figure 6 and 7 presents the fuzzy inference and surface view of fuzzy model for relative hazard rating.

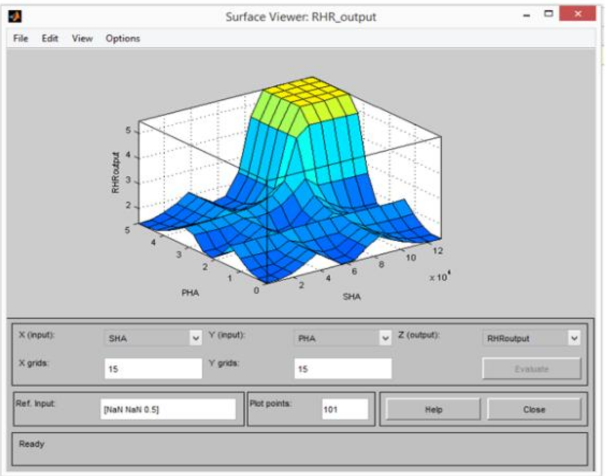


Input: [8.439e+004 3.875 0.6036]

Plot points: 101

Opened system RHR_output, 27 rules

Fig. 6: Fuzzy Inference of RHR Output Rating Fuzzy Model



X (input): SHA

Y (input): PHA

Z (output): RHRoutput

X grids: 15

Y grids: 15

Ref. Input: [NaN NaN 0.5]

Plot points: 101

Ready

Fig. 7: Surface View of RHR Output Rating Fuzzy Model

The relative hazard rating showed value of 1.72 and 1.65 for both dumpsites. This indicates low contamination mainly due to the absence of hazardous waste material within the dumpsite as most materials are biodegradable.

V. CONCLUSION

This paper explores the hydrogeologic impact of uncontrolled open dumpsites using the electrical resistivity method of Schlumberger (Vertical Electrical Sounding) and fuzzy logic prediction methodology. The interpreted geophysical data delineated the presence of contaminant, the boundaries of the leachates plume. The dumpsites within the study area have produced relatively little leachate which may not infiltrated into the ground water system. This is corresponded with the low values of relative hazard rating obtained from the sites. It is recommended that the dumpsites be monitored for leachate migration through the delineated subsurface fractured zone to avoid risks of contaminations of groundwater. Distances/stations identified as fractures along the foot of the dumpsites though with good groundwater potential should not be chosen as location for borehole drilling so as to avoid contamination.

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