Journal of Environment Pollution and Human Health, 2018, Vol. 6, No. 3, 110-120
Available online at http://pubs.sciepub.com/jephh/6/3/4

DOI:10.12691/jephh-6-3-4

Generic Assessment Criteria for Human Health Risk Assessment of Petroleum Hydrocarbons in Niger Delta Region of Nigeria

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Received July 05, 2018; Revised August 16, 2018; Accepted August 22, 2018

Abstract Oil pollution in the Niger Delta region of Nigeria is widely reported in literature, the local people in this region face serious health risks caused by exposure to petroleum hydrocarbons (PAHs) while performing daily land use activities; through exposure pathways like inhalation, ingestion and dermal contact. Prolong exposure to these contaminants has been proven to be hazardous to human health. Therefore a thorough understanding of the frequency and magnitude of these exposures, as well as the consequences it has on human health can help develop appropriate mitigation measures. Generic Assessment Criteria (GAC) is derived using widely applicable assumptions about the characteristics and behaviour of contaminants; identify potential pathways and susceptible receptors. Such GACs help to provide nationally consistent guidance for assessing human health risks associated with contaminated sites. Since there is currently no GAC for PAHs in Nigeria, this study developed the GAC for aliphatic and aromatic hydrocarbons for three rural land use scenarios, using appropriate algorithms and physicochemical parameters of the local people, to determine the concentration at which hydrocarbons may pose risk to human health, susceptible receptors and predominant pathways relative to land use using CLEA v1.6.

Keywords: *human health risk assessment, Generic Assessment Criteria, PAHs, exposure pathways*

Cite This Article: Shittu Whanda Ja'afaru, and Yuanyuan Cheng, "Generic Assessment Criteria for Human Health Risk Assessment of Petroleum Hydrocarbons in Niger Delta Region of Nigeria." *Journal of Environment Pollution and Human Health*, vol. 6, no. 3 (2018): 110-120. doi: 10.12691/jephh-6-3-4.

1. Introduction

Human health risk assessment (HHRA) is performed to evaluate human exposure to environmental contaminants and the impact on human health, building on information collected on type, composition, frequency and magnitude of exposure. Exposure usually occurs where pollutant linkages exist; a pollutant linkage is established when there is connection between a contaminant in an environmental medium and human receptor via a certain pathway. This pollutant linkage can be simple unconscious hand-to-mouth contact, from cloth to skin, from consumption of home-grown products cultivated on contaminated land, to tracking of contaminants into homes, etc. [1]. For this evaluation, Generic Assessment Criteria (GAC) are developed based on generic assumptions of the behaviour and characteristics of contaminants in different land-use scenarios [2,3,4] and their tendency to enter into the human system. Many countries, including the US, the UK, the Netherlands, and Canada, have developed their respective GACs, with which they provide a nationally consistent guideline for determining whether or not a site poses potentially unacceptable level of risk and requires further assessment or remediation [2]. Extensive research has been done on HHRA of different land-use scenarios, including residential, commercial/industrial, in those countries [3,5,6] leading to the development of relevant technical frameworks.

However, little work has been done for human receptors in rural setting, for example in oil producing areas of Nigeria. Oil spillage/pollution in the Niger Delta region of Nigeria is widely reported in literature, and local people in this region face serious health risks caused by exposure to petroleum hydrocarbons (PAHs) while performing daily activities through pathways such as inhalation, ingestion and dermal contact. There is no GAC available in Nigeria for assessing petroleum contaminants nor is there a regulatory framework for assessing and managing contaminated lands in Nigeria [7]. Although Nigeria is signatory to several international conventions on pollution, waste management, only the Environmental Guidelines and Standards for Petroleum Industries in Nigeria (EGASPIN) used in the oil sector came close to addressing land and water pollution in oil fields for remediation purposes only. In order to thoroughly understand the frequency and magnitude of exposure, as well as the consequences to human health, this study derived (GAC) for assessing hydrocarbon contaminants from oil spills for oil producing communities in the Niger Delta region of Nigeria. The

GAC is compared with the United Kingdom's established national standard used in contaminated land management to evaluate the magnitude of risk. Since Nigeria does not have a coherent contaminated land definition, the UK definition may suffice i.e. contaminated land under Part 2A of the Environmental Protection Act 1990 which defines contaminated land as: "*any land… by reason of substances in, on or under the land, that; a) significant harm is being caused or there is a significant possibility of such harm being caused or; b) pollution of controlled waters is being, or is likely to be caused*" [8].

Petroleum production began in Nigeria in 1956 from Oloibiri village in Bayelsa state with a modest daily output of between 5,100 and 6,000 barrels, while export began in 1958 [9,10,11]. Following the discovery, several Multinational Oil Companies (MOCs) proliferated the Niger Delta region to prospect and produce oil, such that as at 2004 Nigeria has reached a production level of 2.5 million barrels per day with plans to increase to 4.5 million barrels per day in the near future [9,10,11,12,13]. The proliferation of these oil companies is manifested in the number of oil wells and other facilities; according [10] between 1960 and 1985, a total of 3,525 oil wells were drilled, such that as at 2012 there are more than 5,284 oil wells [14,12], about 606 oil fields (355 onshore and 251 offshore) and more than 527 flow-stations, and ten export terminals operated by Shell, Chevron, Exxon Mobil and Agip. A network of pipelines linking these facilities with the ports and inland storage and collection depots [15,16,17,18,19,20] traverses through oil producing communities thereby exposing the communities to incidental discharge/spill and prolonged exposure to hydrocarbons and gas flaring, all of which can lead to serious adverse human health conditions in oil producing communities.

During the last two decades, oil interdiction, oil theft, bunkering and artisanal refining have become popular not only as a form of protest on environmental injustice against the government and MOCs' poor corporate social responsibility (CSR) and unfriendly environmental practices, but as a process of civil disobedience to claim direct resource control and benefit [21,22,23,24], this is causing significant damage to the environment with serious repercussion for land use and implication on human health. The series of protests and agitations against oil pollution and its impact in the Niger Delta prompted the Federal Government of Nigeria to in 2009 commission the United Nations Environment Programme (UNEP) to assess polluted sites in Ogoniland [24,25]. The [25] report revealed presence of petroleum hydrocarbon contaminants in the environment at several concentrations higher than most international standards, and was however silent on land use exposure or assessment criteria; thereby relegating human health risk-assessment as an integral variable in remediation process. Of concern is lack of adherence to the Oil Pipeline Act of 1956 regulation by the people, the regulation requires a 30-metre right of way (ROW) for pipelines, but this is not being enforced as homesteads and farmlands have already encroached on several ROWs [26] thereby increasing proximity and chances of exposure whenever oil spill occur from pipelines. This paper derive GAC for performing HHRA arising from exposure to petroleum hydrocarbon (oil spill) contaminants for three typical rural land use activities identified in oil producing communities of the Niger Delta.

2. Methodology

The study area is located in the south-south geopolitical zone of Nigeria, commonly referred to as the Niger Delta region where the bulk of Nigeria's petroleum exploration and exploitation takes place (Figure 1). This is a heavily polluted area due to oil spills from oil well, storage facilities and pipelines caused by operational error, sabotage, accident etc [7]. Most traditional homes/farms in the area are located close to pipeline right of way or oil wells, which increases proximity to migrating hydrocarbon plume and direct exposure tendency.

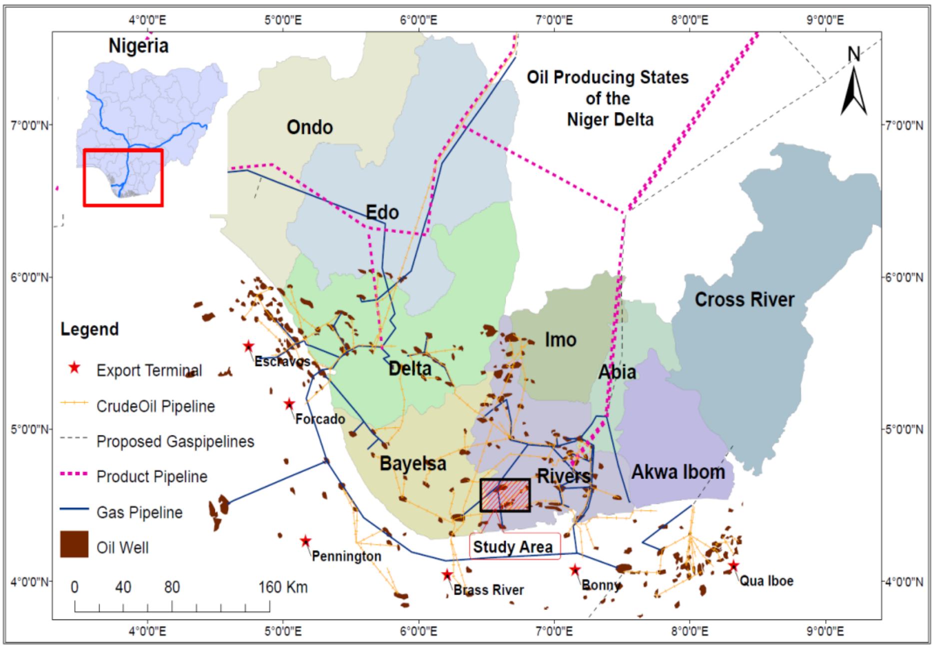

Figure 1. Offshore and onshore oil production infrastructure in the oil-producing Niger Delta States of Nigeria (Source: *The Petroleum Economist*, 2005)

The GAC were derived using CLEA (contaminated land exposure assessment) model v1.06. This software was developed by the UK Environmental Agency for deriving generic soil assessment criteria base on general assumptions on the characteristics of suspected contaminants and receptors (people) on site. CLEA uses a series of equations to predict, or simulate, exposure to a critical receptor from a given soil concentration via a number of exposure pathways. The critical receptor is dependent on land use [26] are can be referred to as an individual or group of people in a population that are likely to become exposed or susceptible to the contaminant present [27]. The software allows users to enter site-specific data for soil assessment criteria on the characteristics of contaminants and people present on site using non-generic approach to assess whether a measured concentration of contaminants in soil can present potential risk to human health under specific circumstances [28]. Although an upgraded version of the CLEA software v1.071 was published in 2015, the upgrade did not have any effect on the results obtained using CLEA v1.06. (The major update to v1.017 is addition of new chemicals that has no bearing on the chemicals treated in this paper).

In assessing the land use activities, physico-chemical properties of aromatic and aliphatic equivalent carbon (EC) number/fractions (Table 1) that were used to derive the LQM/CIEH GAC for petroleum hydrocarbon fractions [29], and human exposure parameters gathered from questionnaires and literature materials were used to modify default settings in the software. Consequently GAC for four Soil Organic Matters (SOMs) categories at 1%, 2.5%, 5% and 10% was calculated for sandy clay loam soil, (the higer the SOM, the higher the adherence capacity of the soil materials) which has been adjudged to be prevalent in the area [25], and from wide consultation and expert elicitation, as against the UK Environment Agency of 1%, 2.5% and 6% reported in the LQM/CIEH [29]. The GAC for individual land use is defined as the concentration of hydrocarbon fractions in soil at which the Average Daily Exposure (ADE) calculated in CLEA v1.06 represents the Health Criteria Value (HCV).

Table 1. Tolerable Daily Intake values for both oral ingestion and inhalation (TDI_{oral} and TDI_{inhel})

Fraction	TDI_{oral} μg kg^{-1} day^{-1}	TDI_{inhal} μg kg^{-1} day^{-1}	Source
Aliphatic			
EC5-EC6	5000	5000	TPHCWG
>EC6-EC8			
>EC8-EC10	100	290	TPHCWG
>EC10-EC12			
>EC12-EC16			
>EC16-EC35	2000	N/A	TPHCWG
>EC35-EC44	2000	N/A	API
Aromatic			
EC5-EC7	223	1400	Toluene TOX report
>EC7-EC8			
>EC8-EC10	40	60	TPHCWG
>EC10-EC12			
>EC12-EC16			
>EC16-EC21	30	N/A	TPHCWG
>EC21-EC35			
>EC35-EC44	30	N/A	API
Aromatic and Aliphatic			
>EC44-EC70	30	N/A	API

*TPHCWG- Total Petroleum Hydrocarbon Working Group,
** API- American Petroleum Institute
*** TOX- UK Environment Agency Toxicology report.

2.1. Determining Exposure Scenarios

Exposure duration (ED) is the time spent conducting a particular activity while averaging time (AT) is the number of days in a year multiplied by the age of a receptor [27,28]. Thus AT can be determined with Equation 1, for example the AT for a six-year-old child would be 2,190 days, being the number of days in a year multiplied by six which is the age of the child [27] as shown below.

$$AT_{(age)} = 365 \times 6 = 2{,}190. \quad (1)$$

Study conducted among 250 randomly selected individuals in 10 selected oil producing communities; indicate that about 87% of respondents spend at minimum four hours a day, four to five days a week on either the farm, or on fishing ground, or wild gathering, or hunting etc. [7].

3. Land Use Exposure

Two exposure scenarios are envisaged, first is exposure due to the presence of polluted media (soil, water, air etc.) around a homestead and, secondly exposure due to contamination of land-use sites e.g. farmland, fishing ground, playground etc. The first scenario depicts a long-term continuous indoor and outdoor exposure as people spend time at home; the second is not continuous because outdoor activities are time specific. For the purpose of this paper, focus is on outdoor land use activities that are time, day and season specific.

Outdoor land use comprise of all land-use activities undertaken to meet daily sustenance and economic requirement of a household, which may be performed on allotments (gardens) near homes or on marginal fields far from homes. Availability of land and household size often determine the scale and size of land put in use by typical rural families in Nigeria, although land ownership (including dry land, pond, swamp and forest) in most communities is through clan, inheritance, conquest, donation, rent and purchase [25]. Rural people tend to practise small-scale agriculture with intensive labour and total reliance on seasons [29,30,31,32]. These outdoor land-uses often reflect the socio-economic level (rich or poor) and lifestyle of the people, which may also differ from place to place and culture.

This paper investigates the characteristics of outdoor land-use activities performed by native of the oil producing communities, by looking at the day-to-day livelihood to gather information on how, whom, what and when it is being performed, the scale and the duration. Based on this information, a potential land-use exposure scenario was developed. Naturally, the environment where people live, shape their culture; and culture by itself has influence on land-use participation. Consequently, it is common in an African rural setting to find specific tasks allocated to particular age group or gender; for example fetching water from streams, firewood collection, cooking etc. are mainly reserved for the female gender and younger children [30]. Hence, traditional allocation makes it easy to identify the critical receptor for each land use exposure scenario being investigated. For this purpose the outdoor land-use activities were categorised into three types: i) rural agricultural land use (consisting of farming, fishing, wild gathering, and hunting), ii) rural informal dwelling, and iii) rural standard residential. While the last two may have indoor exposures, this paper is concerned with outdoor exposure. The potential exposure pathways and the critical receptors considered are indicated in Table 2.

Table 2. Potential exposure pathways and critical receptors for rural land uses

	Rural Land Uses		
	Agriculture	Informal Dwelling	Standard Residential
Critical receptor	0-16 yrs male child	0 to 17 yrs female	0 to 16 yrs male
Age Class	1-16	1-17	1-16
Exposure pathways			
Inhalation of vapour (outdoor)	√	√	√
Inhalation of soil-derived dust (outdoor)	√	√	√
Ingestion of soil attached to vegetables	√		
Ingestion of soil and dust	√	√	√
Ingestion of contaminated water	√	√	√
Dermal contact with soil and dust	√	√	√
Consumption of home -grown vegetables	√	√	√

3.1. Rural Agricultural Land Use

Rain fed agriculture depends mainly on seasonal pattern of the rainy season. For instance, farming takes about six months from cultivation to harvest (depending on crop). Fishing on the other hand is favourable in the dry season [31,32] when the river level is low. Wild gathering is done throughout the year because produce is freely available both in the rainy season, e.g. snails, palm kernels, periwinkles, edible insects, fruits, vegetables etc., and in the dry season, e.g. materials like dry wood, herbs, tree fruits etc. Since most rural production is on the subsistence level [33,34,35], households take advantage of seasonal patterns to partake in different land use to sustain their families through the year. For this land use, an area with repeated history of oil spill incidence and polluted fields is envisaged (Figure 2), since the people are mostly poor and there is scarcity of land in the area, they are unable to relocate [36,37]. There are 7 possible exposure pathways (Table 2) for the rural agricultural land use (RALU) and the critical receptor would be a 16 year old child (male and female) who are more vulnerable due to lower bodyweight [2,5].

3.2. Rural Informal Dwelling

This scenario represents small less-populated rural dwellings in its early formative stage (Figure 3). These dwellings are constructed with combustible materials like palm leaves, wooden sticks and grasses; there are no concrete floors, slabs, roads, or pavements. The homesteads are sparsely distributed with spaces in-between for small-scale gardening. The source of water is from local streams, ponds, and hand-dug wells. Less than 45% of rural communities in Nigeria have improved source of drinking water [38]; as such, many rural communities depend on natural sources. The inhabitants depend solely on materials obtained from the local ecosystem. The assessment for rural informal dwelling (RID) considered that a female adult is assumed to spend the greater part of her time at home close to pipeline right of way or an area with repeated history of oil spill incidence such as in Figure 3.

Figure 2. Farms located along an oil-polluted river [25]

Figure 3. A typical informal rural homestead [25]

Figure 4. Rural residential settlements [25]

3.3. Rural Standard Residential

This form of settlement is relatively organised with market square, the homesteads are close together with larger population than the informal dwellings in Figure 2. Houses are constructed with concrete materials, pavements and paved roads (Figure 4). There is limited land available for any form of cultivation; people would normally travel outside the community to farm or gather. The small patches of land available are used for small gardens or allotments; the source of drinking water is from community boreholes and open streams. The common exposure pathways associated with the rural standard residential (RSR) land use are provided in Table 2, receptors aged 1- 16 years playing on/close to oil spill sites are considered as the critical receptors.

4. Results and Discussion

4.1. Deriving the Generic Assessment Criteria (GAC)

The GAC for aliphatic and aromatic fractions' parameters in LQM/CIEH were adopted to derive equivalent carbon (EC) fractions for use in rural land-use human health risk assessment using CLEA v1.06. The land uses described were defined in accordance with the risk-based contaminated land management framework in which historic and current land use, contaminants' fate, transport, and toxicity forms the basis [2]. Consequently, exposure scenarios were developed in isolation, assuming time spent on a single land use at a time. Due to lack of published work in this area in Nigeria, physico-chemical parameters in LQM/CIEH for related TPH EC fractions [29] were adopted. Different soils have different capacity to accummulate different amount of contaminants, depending on the amount of soil organic matter (SOM) it contain, hence the use of SOM to determine comcentration of contaminats especially for total hydrocarbons in soils. The GAC values for the petroleum hydrocarbon EC numbers for the respective rural land use are presented in Table 3 and Table 4 for 1%, 2.5%, 5% and 10% SOM respectively. GAC values in shaded cells are those that exceed solubility and vapour saturation limits (ie the concentration at which soil is saturated with the chemical and the adsorptive limits of the soil and volatility in air have been reached) indicated in brackets under the soil saturation concentration column. The average daily exposure health criteria value (ADE:HCV) ratio and percentage contibutions of each exposure pathways are given in Table 5, Table 6 and Table 7.

4.2. Exposure Pathway Contributions

The contributions of each exposure pathway for respective land use at exposure contribution of 1% and 5% SOM was done to compare variations; the results indicate no significant difference (Table 5, Table 6 and Table 7). The most significant exposure pathways in rural agricultural land use include direct soil ingestion of aliphatic EC>16-35, EC>35-44, aromatic EC>5-7, EC>7-8, EC>16-21, EC>21-35, EC>35-44 and aliphatic and aromatic EC>44-70. Background oral is significant in the total exposure of all fractions, while background inhalation is higher in aliphatic EC>16-35, EC>35-44 and aromatic EC>16-21 to EC>35-44. Dermal contact with soil has 0.01% contribution for some fractions, while dust and consumption of home-grown produce and attached soil is significant for the lighter aliphatic and aromatic. All the exposure pathways contributed in rural informal dwelling land use. However, the most significant pathways are direct soil ingestion, consumption of home-grown produce and attached soil, inhalation of indoor and outdoor vapour, and background oral and inhalation. There is no remarkable difference in exposure pathway contribution for 1% and 5% SOM. For the rural standard residential, all exposure pathways were involved with the exception of inhalation of dust. The less significant is direct soil ingestion of EC>5-6 (Aliphatic) and EC>5-7 and EC>7-8 (Aromatic), while higher EC fractions are the most significant for both aliphatic and aromatic for direct soil ingestion.

Table 3. Land use GAC at 1% and 2.5% Soil Organic Matter (mg/kg)

	1% Soil Organic Matter (mg/kg)				2.5% Soil Organic Matter (mg/kg)			
TPH Fraction	**RALU***	**RID***	**RSR***	**SSC* (mg/kg)**	**RALU**	**RID**	**RSR**	**SSC (mg/kg)**
Aliphatic								
EC5-6	264.00	109.00	178.00	340.00	280.00	138.00	254.00	558.00
EC>6-8	283.00	142.00	275.00	144(vap)	289.00	160.00	325.00	322.00(sol)
EC>8-10	7.87	4.45	9.57	55.80	7.89	4.61	9.83	136.00
EC>10-12	7.90	4.64	9.96	47.50	7.90	4.65	10.50	118.00
EC>12-16	7.91	5.04	10.50	23.70	7.91	5.33	10.50	59.10
EC>16-35	43.80	31.50	58.20	8.48(sol)	43.80	31.90	58.20	21.20(sol)
EC>35-44	43.80	31.50	58.20	8.48(sol)	43.80	31.90	58.20	21.20(sol)
Aromatic								
EC5-7	22.50	5.31	6.99	1220.00	27.00	8.49	12.20	2260.00
EC>7-8	25.90	7.55	10.60	869.00	29.80	11.60	18.40	1920.00
EC>8-10	7.87	4.54	9.57	55.80	7.89	4.61	9.83	136.00
EC>10-12	7.90	4.64	9.96	47.50	7.90	4.65	10.50	118.00
EC>12-16	7.91	5.04	1.50	23.70	7.91	5.33	10.50	59.10
EC>16-21	2.29	1.60	2.78	0.0154(sol)	2.30	1.67	2.95	0.04(vap)
EC>21-35	2.31	1.70	3.04	4.83	2.31	1.72	3.06	12.10
EC>35-44	43.80	31.50	58.20	8.48(sol)	43.80	31.90	58.20	21.20(sol)
EC>44-70	2.31	1.72	3.07	0.29(sol)	2.31	1.73	3.07	0.73(sol)

*Rural Agricultural Land Use (RALU); Rural Informal Land Use (RID); Rural Standard Residential (RSR); Soil Saturation Concentration (SSC).

Table 4. Land use GAC at 5% and 10% Soil Organic Matter (mg/kg)

TPH Fraction	5% Soil Organic Matter (mg/kg)				10% Soil Organic Matter (mg/kg)			
	RALU	RID	RSR	SSC (mg/kg)	RALU	RID	RSR	SSC (mg/kg)
Aliphatic								
EC5-6	286.00	153.00	300.00	981.00	289.00	162.00	331.00	1830.00
EC>6-8	291.00	166.00	347.00	618.00	292.00	169.00	359.00	1210.00
EC>8-10	7.90	4.63	9.92	270.00	7.90	4.64	10.40	539.00
EC>10-12	7.91	4.83	10.50	236.00	7.91	5.11	10.50	472.00
EC>12-16	7.91	5.49	10.50	118.00	7.91	5.61	10.50	236.00
EC>16-35	43.80	32.10	58.20	42.40(sol)	43.80	32.30	58.20	84.80
EC>35-44	43.80	32.10	58.20	42.40(sol)	43.80	32.30	58.20	84.80
Aromatic								
EC5-7	29.70	11.50	18.10	4010.00	31.50	14.40	24.90	7500.00
EC>7-8	31.60	14.50	26.10	3660.00	32.70	17.60	32.90	7150.00
EC>8-10	7.90	4.63	9.92	270.00	7.90	4.64	10.40	539.00
EC>10-12	7.91	4.83	10.50	236.00	7.91	5.11	10.50	472.00
EC>12-16	7.91	5.49	10.50	118.00	7.91	5.61	10.50	236.00
EC>16-21	2.31	1.70	3.01	0.08(sol)	2.31	1.71	3.04	0.15(vap)
EC>21-35	2.31	17.30	3.07	24.10	2.31	1.73	3.07	48.30
EC>35-44	43.80	32.10	58.20	42.40(sol)	43.80	32.30	58.20	84.80
Aliphatic and Aromatic								
EC>44-70	2.31	1.73	3.08	1.45(sol)	2.31	1.73	3.08	2.91(sol)

*Rural Agricultural Land Use (RALU); Rural Informal Land Use (RID); Rural Standard Residential (RSR); Soil Saturation Concentration (SSC).

Table 5. Pathway contribution to total exposure for rural agricultural land use (RALU) calculated using CLEA v1.06 for 1% and 5% SOM

	ALIPHATIC							AROMATIC								
	EC5-6	EC>6-8	EC>8-10	EC>10-12	EC>12-16	EC>16-35	EC>35-44	EC>5-7	EC>7-8	EC>8-10	EC>10-12	EC>12-16	EC>16-21	EC>21-35	EC>35-44	EC>44-70
ADE to HCV ratio																
Oral ADE to HCV ratio at GAC	0.50	0.50	0.82	0.82	0.82	0.14	0.14	0.86	0.86	0.82	0.82	0.82	0.78	0.78	0.14	0.78
Inhalation ADE to HCV ratio at GAC	0.50	0.50	0.18	0.18	0.18	0.86	0.86	0.14	0.14	0.18	0.18	0.18	0.22	0.22	0.86	0.22
Per cent (%) pathway exposure contribution (1%) SOM for rural agricultural land use																
Direct soil ingestion	22.48	24.12	24.87	24.98	24.99	33.32	33.32	32.86	38.16	24.87	24.98	24.99	32.97	33.29	33.32	33.31
Consumption of home-grown produce and attached soil	2.51	0.87	0.12	0.01	0.00	0.00	0.00	16.61	11.66	0.12	0.01	0.00	0.35	0.04	0.00	0.01
Dermal Contact with soil and dust	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation of dust	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inhalation of vapour (indoor)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inhalation of vapour (outdoor)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Background (oral)	25.00	25.00	25.00	25.00	25.00	33.33	33.33	0.01	0.05	25.00	25.00	25.00	33.33	33.33	33.33	33.33
Background (inhalation)	25.00	25.00	25.00	25.00	25.00	0.00	0.00	1.02	0.26	25.00	25.00	25.00	0.00	0.00	0.00	0.00
Per cent (%) pathway exposure contribution (5%) SOM for rural agricultural land use																
Direct soil Ingestion	24.39	24.81	24.97	24.99	24.99	33.32	33.32	43.48	46.60	24.97	24.99	24.99	33.25	33.32	33.32	33.32
Consumption of home-grown produce and attached soil	0.60	0.18	0.02	0.00	0.00	0.00	0.00	5.99	3.23	0.02	0.00	0.00	0.07	0.01	0.00	0.00
Dermal Contact with soil and dust	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation of dust	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inhalation of vapour (indoor)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inhalation of vapour (outdoor)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Background (oral)	25.00	25.00	25.00	25.00	25.00	33.33	33.33	0.01	0.05	25.00	25.00	25.00	33.33	33.33	33.33	33.33
Background (inhalation)	25.00	25.00	25.00	25.00	25.00	0.00	0.00	1.02	0.26	25.00	25.00	25.00	0.00	0.00	0.00	0.00

Table 6. Relevant pathway contribution to total exposure for rural informal dwelling (RID) calculated using CLEA v1.06 for 1% and 5% SOM

	ALIPHATIC							AROMATIC								
	EC5-6	EC>6-8	EC>8-10	EC>10-12	EC>12-16	EC>16-35	EC>35-44	EC>5-7	EC>7-8	EC>8-10	EC>10-12	EC>12-16	EC>16-21	EC>21-35	EC>35-44	EC>44-70
ADE to HCV ratio																
Oral ADE to HCV ratio at GAC	0.50	0.05	0.82	0.82	0.82	0.14	0.14	0.86	0.86	0.82	0.82	0.82	0.78	0.78	0.14	0.78
Inhalation ADE to HCV ratio at GAC	0.50	0.50	0.18	0.18	0.18	0.86	0.86	0.14	0.14	0.18	0.18	0.18	0.22	0.22	0.86	0.22
Per cent (%) pathway exposure contribution (1%) SOM for rural informal dwelling																
Direct soil ingestion	12.44	16.56	19.18	19.80	21.30	31.98	31.98	10.38	14.52	19.18	19.60	21.30	30.86	32.99	31.98	33.18
Consumption of home-grown produce and attached soil	9.19	3.65	0.62	0.08	0.01	0.00	0.00	36.29	30.21	0.62	0.08	0.01	2.17	0.25	0.00	0.06
Dermal Contact with soil and dust	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation of dust	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation of vapour (indoor)	0.34	0.46	0.53	0.54	0.03	0.00	0.00	0.29	0.40	0.53	0.54	0.03	0.00	0.00	0.00	0.00
Inhalation of vapour (outdoor)	3.02	4.02	4.66	4.76	3.64	1.32	1.32	2.52	3.53	4.66	4.76	3.64	0.27	0.07	1.32	0.07
Background (oral)	25.00	25.00	25.00	25.00	25.00	33.33	33.33	0.02	0.05	25.00	25.00	25.00	33.33	33.33	33.33	33.33
Background (inhalation)	25.00	25.00	25.00	25.00	25.00	0.00	0.00	1.02	2.61	25.00	25.00	25.00	0.00	0.00	0.00	0.00
Per cent (%) pathway exposure contribution (5%) SOM for rural informal dwelling																
Direct soil Ingestion	17.43	18.94	19.56	20.40	23.20	32.70	32.70	22.43	28.00	19.56	20.40	23.20	32.71	33.22	32.70	33.26
Consumption of home-grown produce and attached soil	2.84	0.92	0.13	0.02	0.00	0.00	0.00	20.97	13.07	0.13	0.02	0.00	0.46	0.05	0.00	0.02
Dermal Contact with soil and dust	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation of dust	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation of vapour (indoor)	0.48	0.53	0.54	0.05	0.01	0.00	0.00	0.62	0.78	0.54	0.05	0.01	0.00	0.00	0.00	0.00
Inhalation of vapour (outdoor)	4.23	4.60	4.75	4.52	1.77	0.60	0.60	5.45	6.80	4.75	4.52	1.77	0.13	0.03	0.60	0.03
Background (oral)	25.00	25.00	25.00	25.00	25.00	33.33	33.33	0.02	0.05	25.00	25.00	25.00	33.33	33.33	33.33	33.33
Background (inhalation)	25.00	25.00	25.00	25.00	25.00	0.00	0.00	1.02	2.61	25.00	25.00	25.00	0.00	0.00	0.00	0.00

Table 7. Relevant pathway contribution to total exposure for rural standard residential (RSR) calculated using CLEA v1.06 for 1% and 5% SOM

	ALIPHATIC							AROMATIC								
	EC>5-6	EC>6-8	EC>8-10	EC>10-12	EC>12-16	EC>16-35	EC>35-44	EC>5-7	EC>7-8	EC>8-10	EC>10-12	EC>12-16	EC>16-21	EC>21-35	EC>35-44	EC>44-70
ADE to HCV ratio																
Oral ADE to HCV ratio at GAC	0.50	0.50	0.82	0.82	0.82	0.14	0.14	0.86	0.86	0.82	0.82	0.82	0.78	0.78	0.14	0.78
Inhalation ADE to HCV ratio at GAC	0.50	0.50	0.18	0.18	0.18	0.18	0.86	0.14	0.14	0.18	0.18	0.18	0.22	0.22	0.86	0.22
Per cent (%) pathway exposure contribution (1%) SOM for rural standard residential																
Direct soil ingestion	11.43	17.64	22.73	23.67	24.94	33.30	33.30	7.69	11.44	22.73	23.67	24.94	30.06	32.93	33.30	33.22
Consumption of home-grown produce and attached soil	13.00	6.47	1.13	0.14	0.01	0.01	0.01	41.41	26.67	1.13	0.14	0.01	3.26	0.38	0.01	0.10
Dermal Contact with soil and dust	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Inhalation of dust	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inhalation of vapour (indoor)	0.56	0.87	1.12	1.17	0.03	0.00	0.00	0.38	0.56	1.12	1.17	0.03	0.00	0.00	0.00	0.00
Inhalation of vapour (outdoor)	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Background (oral)	25.00	25.00	25.00	25.00	25.00	33.33	33.33	0.01	0.05	25.00	25.00	25.00	33.33	33.33	33.33	33.33
Background (inhalation)	25.00	25.00	25.00	25.00	25.00	0.00	0.00	1.01	2.59	25.00	25.00	25.00	0.00	0.00	0.00	0.00
Per cent (%) pathway exposure contribution (5%) SOM for rural standard residential																
Direct soil Ingestion	19.22	22.21	23.57	24.89	24.97	33.31	33.31	19.87	28.25	23.57	24.89	24.97	32.60	33.23	33.31	33.29
Consumption of home-grown produce and attached soil	4.82	1.67	0.24	0.03	0.01	0.01	0.01	28.62	20.31	0.24	0.03	0.01	0.71	0.08	0.01	0.02
Dermal Contact with soil and dust	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Inhalation of dust	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inhalation of vapour (indoor)	0.95	1.10	1.16	0.05	0.01	0.00	0.00	0.98	0.09	1.16	0.05	0.01	0.00	0.00	0.00	0.00
Inhalation of vapour (outdoor)	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Background (oral)	25.00	25.00	25.00	25.00	25.00	33.33	33.33	0.01	0.05	25.00	25.00	25.00	33.33	33.33	33.33	33.33
Background (inhalation)	25.00	25.00	25.00	25.00	25.00	0.00	0.00	1.01	2.59	25.00	25.00	25.00	0.00	0.00	0.00	0.00

4.3. Determining Critical Human Receptor

This aspect was analysed using reported concentration of benzene in air [25] to assess long-term average daily exposure through inhalation. Since there are no officially-documented estimates for inhalation rates for either adults or children in Nigeria, the 95th percentile of the long-term inhalation rate according to age recommended by the [6] (Table 8) was adopted. Noting the influence of climate and labour intensity in the Niger Delta, inhalation rates would be considerably different (higher). Hence, the [6] recommended inhalation rates for each age group are incrementally increased at 10% intervals i.e. 20%, 30%, 40% and 50%, to investigate the implication of higher inhalation rate on average daily exposure. By using [25] reported concentration of benzene in air at 48.20µg/m^3 (0.0482mg/m^3) in Ogoniland, variation in intake via air inhalation between adults and children was demonstrated with the CLEA average daily exposure (ADE) formula (Equation 4). The CLEA equation (Equation 5) was segregated for specific exposure route (inhalation). Also, the 95th percentile body weights for rural communities in Nigeria were derived for 5-30 years from [39]; the GAC averaging time for rural agricultural land use was substituted in the equation. Firstly, the intake rate was obtained from Equation 2 for to arrive at Table 8.

$$Intake = Concentration\left(mg / m^3\right) \times Inhalation\,Rate\left(m^3 / day\right) \quad (2)$$

Secondly, the average daily exposure through inhalation (ADE_{Inh}) was determined using Equation 3 and substituting with parameters in Table 9 to arrive at results in Table 10.

$$ADE_{Inh} = \frac{IR_{Inh} \times EF_{Inh} \times ED_{Inh}}{BW \times AT} \quad (3)$$

Where
ADE = average daily exposure to chemical from soil (mg/kg/bw/day),
IR = chemical intake (mg/day),
EF = the exposure frequency (days $year^{-1}$),
ED = the exposure duration (year),
BW = the human body weight (kg)
AT = the averaging time (days),
Note: inh= inhalation.

Table 8. Benzene intake via inhalation.

Age	Inhalation Rate (m^3/day)					Intake (mg/day)				
	USEPA*	+20%	+30%	+40%	+50%	**USEPA**	20%	30%	40%	50%
< 6	14	16.8	18.2	19.6	21	0.67	0.81	0.88	0.94	1.01
7-8	15	18	19.5	21	22.5	0.72	0.87	0.94	1.01	1.08
9-10	17	20.4	22.1	23.8	25.5	0.82	0.98	1.07	1.15	1.23
11-12	22	26.4	28.6	30.8	33	1.06	1.27	1.38	1.48	1.59
13-14	22	26.4	28.6	30.8	33	1.06	1.27	1.38	1.48	1.59
15-16	22	26.4	28.6	30.8	33	1.06	1.27	1.38	1.48	1.59
17-18	25	30	32.5	35	37.5	1.21	1.45	1.57	1.69	1.81
19-20	25	30	32.5	35	37.5	1.21	1.45	1.57	1.69	1.81
21-30	21	25.2	27.3	29.4	31.5	1.01	1.21	1.32	1.42	1.52

*[6]

Table 9. Parameters substituted into Equation 5

Age Year	*BW (kg)	AT (days)	EF (days)	ED (year)	Chemical Intake (IR) mg/day				
					USEPA	20%	30%	40%	50%
<6	25.1	2190	240	6	0.67	0.81	0.88	0.94	1.01
7-8	26.6	2920	240	8	0.72	0.87	0.94	1.01	1.08
9-10	28	3650	240	10	0.82	0.98	1.07	1.15	1.23
11-12	34.8	4380	240	12	1.06	1.27	1.38	1.48	1.59
13-14	40.1	5110	240	14	1.06	1.27	1.38	1.48	1.59
15-16	53	5840	240	16	1.06	1.27	1.38	1.48	1.59
17-18	62	6570	240	18	1.21	1.45	1.57	1.69	1.81
19-20	66.4	7300	240	20	1.21	1.45	1.57	1.69	1.81
21-30	75.1	10950	240	30	1.01	1.21	1.32	1.42	1.52

*[40].

Table 10. Average daily exposure (ADE) according to percentage increment

Age	ADE (mg/kg/bw/day)				
	USEPA	20%	30%	40%	50%
<6 yr	1.77E-02	2.12E-02	2.30E-02	2.47E-02	2.65E-02
7-8yr	1.79E-02	2.14E-02	2.32E-02	2.50E-02	2.68E-02
9-10yr	1.92E-02	2.31E-02	2.50E-02	2.69E-02	2.89E-02
11-12yr	2.00E-02	2.40E-02	2.60E-02	2.81E-02	3.01E-02
13-14yr	1.74E-02	2.09E-02	2.26E-02	2.43E-02	2.61E-02
15-16yr	1.32E-02	1.58E-02	1.71E-02	1.84E-02	1.97E-02
17-18yr	1.28E-02	1.53E-02	1.66E-02	1.79E-02	1.92E-02
19-20yr	1.19E-02	1.43E-02	1.55E-02	1.67E-02	1.79E-02
20-30yr	8.86E-03	1.06E-02	1.15E-02	1.24E-02	1.33E-02
R^2	0.7493	0.7493	0.7493	0.7493	0.7493
Y	-0.0012x	-0.0015x	-0.0016x	-0.0017x	-0.0018x

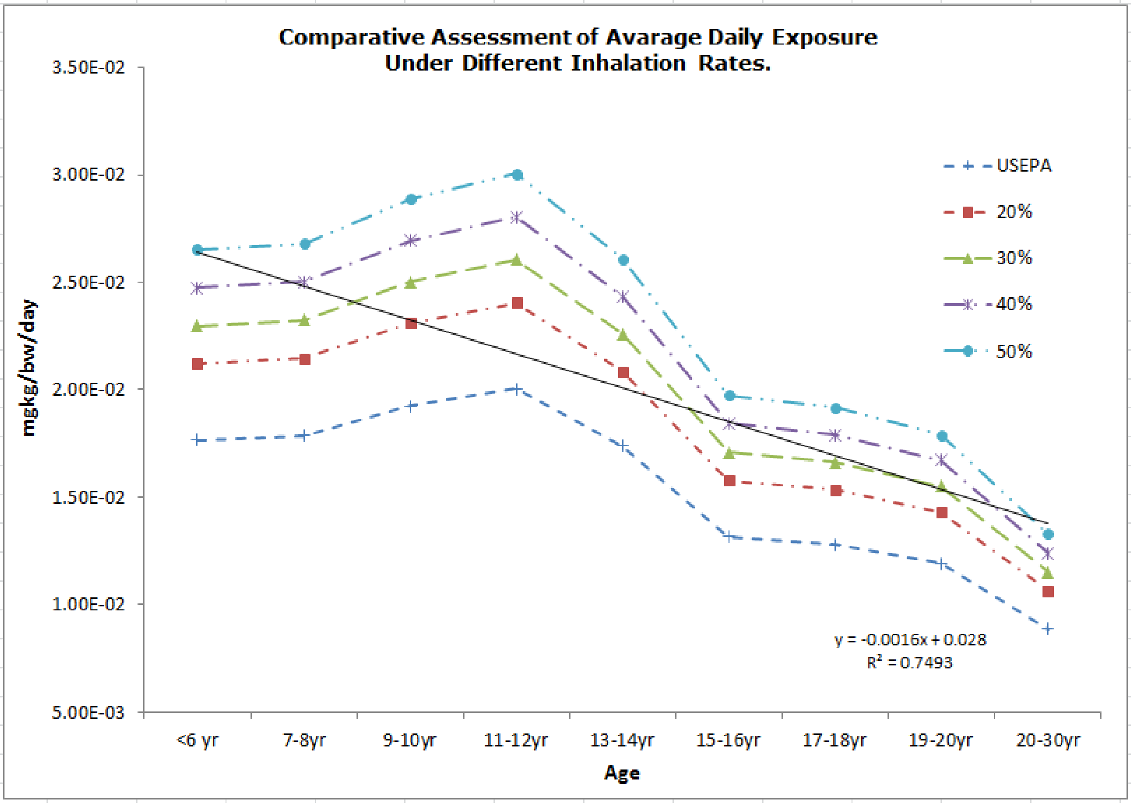

Figure 5. Average daily exposure (inhalation) of benzene by age group

Base on Figure 5, the following deductions can be made on the influence of different inhalation rate on average daily exposure (ADE) through inhalation.

i) That from 6 years to 30 years the increase in inhalation rates results in a proportional increase in critical threshold based on mg/kg/bw/day.
ii) Children aged 12 and lower have higher average daily exposure in terms of concentration on an mg/kg/bw/day basis.
iii) Therefore, if exposed to the same concentration of contaminants, children are more susceptible than adults due to their lower body weight and attenuation time [40].

5. Conclusion

Exposure assessment measures exposure to chemical substances and describes source, pathway, and receptor [5,41]. The result is then compared with national standard to determine whether Health Criteria Value (HCV) (e.g. tolerable daily intake) has been exceeded or not [27]. EGASPIN classified petroleum hydrocarbons under mineral oil with target and intervention values at 50 and 5,000 mg/kg respectively [25], without carbon range. Thus, because EGASPIN is based on a single parameter (mineral oil), the UNEP however, conducted it's analysis and reported in TPH [25]. In addition, the BTEX standards for both soil and groundwater are identical to the Dutch standard which is not suitable, due to lack of consideration for rural land use exposures. Thus the new sets of guideline values derived for TPH (aliphatic and aromatic) in i) rural agricultural land use; ii) rural informal dwelling; and iii) rural standard residential in this paper, provides a building block for adjudicating risk posed to human health from exposure to petroleum hydrocarbon contaminants in Nigeria since the parameters used took into consideration the dynamism of typical rural settings in Nigeria.

In furtherance to establishing a contaminated land use assessment regime in Nigeria, a GAC based on EC number has been developed for aromatic and aliphatic fractions specifically for land use activities in oil polluted areas. By adopting values from the USEPA, LQM/CIEH, the gaps created by lack of risk assessment criteria in Nigeria has been overcome. Therefore the new GAC provide the basis for conducting petroleum hydrocarbon-related human health risk assessment for land use in the Niger Delta in place of the EGASPIN's target and intervention values that was originally developed for soil and ground water remediation by the Dutch. Henceforth, as basis for advancing human health screening standard has been developed, for rural land use in the Niger Delta with the CLEA software. Therefore as new assessment parameters are being developed from laboratories and field experiments in Nigeria, the new values can be introduced into both versions of the software since it allows input of new parameters like land use type, physico-chemical properties, exposure values etc. [27]. The assumption throughout this paper has been on land use activity conducted close to and around oil-polluted sites, and since exposure occurs when a pollutant linkage is established, the essence of proximity becomes a relevant variable. Therefore, considering the proximity of settlements in the study area to pipeline networks and previous oil spill sites, a method for delineating hazard zones from pipeline networks can be found in [7]. For a successful clean-up of Ogoni land, the need to determine exposure scenarios and pollutant linkages cannot be overemphasised, doing this would not only help prioritise the sites, but ensure proper allocation of scarce resources and selection of remediation technique for effective clean up exercise. Thus while some sites may be allowed to undergo natural remediation over time, some must be remediated immediately on the basis of the risk they pose to human health, considering that the most significant pathways are direct soil ingestion, consumption of home-grown produce and attached soil, dermal exposure and inhalation.

Acknowledgments

The authors would like to appreciate the contributions of Prof. Paul Nathanail and Dr. Robert Abrahart who supervised the first author for his PhD during which, the concept to this work was developed, and the Petroleum Technology Development Fund (PTDF) Abuja for sponsoring the research.

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