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ORIGINAL ARTICLE

Heavy metals levels in shellfish from Bodo City and B-Dere, Ogoniland, Rivers State, Nigeria, and evaluation of possible health risks to consumers

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Abstract Heavy metals in the environment have proven to be a major health concern, and there are several health risks associated with it. Seafood consumers are particularly prone to these health risks. This study was designed to investigate heavy metal levels in shellfish from Bodo City and B-Dere, Ogoniland, Rivers State, Nigeria, and to evaluate possible human health risks to consumers of shellfish in these coastal regions. Non-carcinogenic health risk for consumption of shellfish were evaluated using the estimated daily intake (EDI) and target hazard quotients (THQs) for Ni, Cr, As, Cd, Pb, and Fe, while carcinogenic health risk from Ni, Cr, Pb, Cd, As, and Ni was also evaluated. EDI was below the threshold values for Cr but exceeded the threshold for Cd, Pb, As, Ni and Fe. THQs for Cr, Cd, Pb, and Ni were below 1 except for Cd in *U. tangeri* from Bodo City. THQs values for As and Fe were greater than 1 except for Fe level in *C. pallidus* from Bodo City and *U. tangeri* from Bodo City and B-Dere. Also, carcinogenic risk (CR) for Cr in all shellfish exceeded the accepted risk level of 10E−4. Cd CR level for *C. pallidus, T. fucastus, U. tangeri*, and *C. gasar* collected from Bodo City and B-Dere also exceeded the accepted risk level of 10E−4 for As and Ni. CR risk for Pb was below the acceptable range of 10E−4. Consumers of shellfish from Bodo City and B-Dere may be exposed to hazardous metals contamination over a period of time.

Keywords Shellfish · Heavy metals · HHRA · EDI · THQs · CR · Ogoniland

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Introduction

Water and soil contamination from crude oil in Ogoniland is the primary source of heavy metals in the environment, although there are also varieties of industrial and commercial activities, such as shipping, engineering, power production, and manufacturing activities. Moreover, agricultural and domestic effluents may also contribute significant contaminants along the coastal waters in Ogoniland. There is a growing concern that hazardous metals bio-accumulated in fish muscle tissues may represent a major human health risk, especially for populations like those in Ogoniland with high fish consumption rates (Kumar and Mukherjee 2011; Liao and Ling 2003; Diez et al. 2009; Nkpaa et al. 2016). Fish bio-accumulate hazardous metals from the surrounding environment if the following factors are met: long exposure period, the characteristics of the species examined, the levels of the element, and particularly abiotic factors such as pH, seasonal changes, temperature, salinity (Ginsberg and Toal 2009; Copat et al. 2012; Burger and Gochfeld 2009). Hence, harmful substances such as hazardous heavy metals released by anthropogenic sources will be bio-accumulated in aquatic organisms via the food chain. This is because organisms like fishes are constantly exposed to contaminated water and sediment, thus could act as excellent biological markers of heavy metals pollution and non-essential metals because both are taken in and bio-accumulated in their tissues (Kumar and Mukherjee 2011; Canli and Atli 2003). The result is that human health could be at risk because of consumption of fish contaminated by toxic metals (Copat et al. 2012).

Studies on heavy metals bioaccumulation in fish abound, but in recent times, human health risk assessment for populations have become one of the fastest methods used by environmental scientist and regulatory bodies to investigate the impact of hazardous metals on human health and also to investigate and suggest the level of treatment that can solve the environmental problems (Zhang et al. 2012; Storelli and Marcotrigiano 2008; Imar and Carlos 2011; Michael et al. 2011; USEPA 2000). Sometimes the levels of contaminants exceed the permissible limits set by regulatory bodies; this may particularly represent a potential risk for human health.

Human health risk assessment (HHRA) in this study seeks to investigate the bioaccumulation of heavy metals as a result of their mobility in runoff water and crude oil spill and their absorption by shellfish during wet season which have never been investigated before in these regions. HHRA investigates the implications of human activities and weighs the adverse effects to public health. It is becoming one of the fastest and growing methods used currently by environmental toxicologists to evaluate the impact of the hazardous metals bioaccumulation on human health. HHRA of heavy metals on human health from consumption of seafood in this present study is divided into carcinogenic risks (CR) and non-carcinogenic risks such as target hazard quotients (THQ) and estimated daily intake (EDI) (Han et al. 1998; Yabanli and Alparslan 2015). Heavy metals pollution of seafood and its toxicity has become an inevitable challenge nowadays (Orisakwe et al. 2012). It is very important to estimate non-carcinogenic and carcinogenic risks of heavy metals through the consumption of polluted seafood. HHRA protocols were developed by the US Environmental Protection Agency (USEPA) for the assessment of potential health risks associated with long-term exposure to chemical pollutants (USEPA 1989; Kumar et al. 2010a, b; Harmanescu et al. 2011). HHRA has also been used recently by many researchers (Onuoha et al. 2016; Nkpaa et al. 2016; Adeel and Riffact 2014; Amirah et al. 2013; Copat et al. 2012; Kumar and Mukherjee 2011; Yu-jun et al. 2011; Harmanescu et al. 2011; Declan and Andrea 2008; Wang et al. 2005; Chien et al. 2002) and has been very productive.

Oil exploration and production in Ogoniland began in the early 1990s. The oilfields and installations have since largely remained dormant due to civil unrest by the populace. However, major oil pipelines still pass through Ogoniland, and crude oil spills, especially the oil spills in 2008 and 2009, continue to cause environmental degradation in the region due to such factors as illegal artisanal refining, vandalism to oil facilities, and lack of maintenance. This has resulted in contamination of rivers, creeks, agricultural farm, and forest lands (Kinako and Awiwaadu 2000). Previous reports have shown high levels of heavy metals contamination in fishes and water from Kaa, B-Dere and Bodo City in Ogoniland from crude oil contamination during dry season (Nkpaa et al. 2013, 2016).

Heavy metal mobility in runoff water and absorption by sediments and seafood during wet season may contribute significantly to the levels of contaminants (metals) that an exposed population are at risk to in addition to the direct crude oil spill in coastal water as seen in B-Dere and Bodo City, in Gokana Local Government Area, Ogoniand, Rivers State, Nigeria. This kind of contamination clearly contributes to an increase of heavy metals content in the environment. Thus, in these coastal areas, there is a need for systematic and detailed research on the health risk of heavy metals bioaccumulation as a result of their mobility in runoff water and crude oil spill and their absorption by shellfish during wet season. It is pertinent to treat and protect water contaminants from different sources in different ways (Li et al. 2013) to prevent human health risk. Therefore, the aim of this research is to assess the impact of runoff water from contaminated agricultural land and crude oil spill in coastal water on the levels of heavy metals bioaccumulation in shellfish in wet season and consequently, evaluate the Estimated Daily Intake, Target Hazard Quotient, and Carcinogenic Risk provided in the US-EPA Region III risk-based concentration table (USEPA 2000) in order to investigate possible causes for alerts regarding hazards to human health for those who consume shellfish.

Materials and methods

Study area

Samples were collected from Bodo city and B-Dere all in Ogoniland (Latitude 4°40′5″N and 4°43′19.5″N and Longitude 7°22′53.7″E and 7°27′9.8″E), an important and known crude oil producing province in the South-East of Niger Delta, Nigeria (Nkpaa et al. 2016). Ogoniland is known to have a tragic history of pollution from oil spills and oil well fires, although there have been no systematic scientific information available (except the recent UNEP 2011 report) about the ensuing contamination. This region covers some 1000 km^2 in the south-east of the Niger Delta basin. Its population is about 832,000, according to the 2006 National Census. The major source of protein for the people living in these coastal regions is seafood.

Oil activities such as exploration began in Ogoniland in the 1950s and extensive oil exploration and production facilities were established during the first 30 years. These facilities were operated by Shell Petroleum Development Company (Nigeria) Ltd (SPDC), a joint venture between the Nigerian National Petroleum Company (NNPC), Shell International, Elf and Agip. Once these facilities began operation, other issues had to be dealt with, such as spills caused during oil production and the disposal of water (often salty and known as 'produced water') and flaring of gas (produced gases) generated alongside the oil. All these activities and their effects leave an environmental footprint in Ogoniland (UNEP 2011). It is important to note that the majority of seafood consumed in Ogoniland, especially Gokana Local Government Area (LGA), Rivers State, Nigeria, come from the study sites (B—Dere and Bodo City). These research study sites have witnessed many oil spills as a result of bunkering and artisanal crude oil refining activities and pipeline failures. This presents a special health risk to populace consuming seafood from these sites.

Collection of test samples

Four species of shellfish *Callinectes pallidus* (crabs), *Tympanotonus fucastus* (periwinkle), *Uca tangeri* (fiddler crab), and *crassostrea gasar* (oysters) mostly consumed by the populace were collected from two sites (February 02nd, 2016) from B-Dere and Bodo City in Gokana Local Government Area, Ogoniand, Rivers State, Nigeria. The sampling period was during the wet season. Wet season was chosen for this study because of the high consumption rate of shellfish and high surface runoff from contaminated agricultural land experienced around this coastal water in the wet season. At each site, twenty (20) individual shellfish were collected, and dirt and particles were removed by washing with double distilled water. The fishes were subsequently blotted with tissue paper and kept frozen in an ice chest before transportation to the laboratory for analysis (Nkpaa et al. 2016).

Quality assurance and quality control

The selection of species was determined by their feeding habits (sediment feeders) which have significant effect on their metal bioaccumulation and retention except *C. gasar*. Among the analyzed species, *T. fucastus* has accumulation of sediments on the shell which contribute significantly to the extent of metals bioaccumulation. Deionized water which was double distilled and free from dirts was used for the study. Glassware and plastic ware (Merck, Germany) used were rinsed thoroughly with 10% HNO_3 followed by washing with deionized distilled water. For data assurance, the entire test samples were spectrophotometrically analyzed in triplicate. Determination of metals was performed with a GBC Avanta atomic absorption spectrophotometer (ASS) (model: PM ver 2.02 Avanta). The analytical blanks used in the study were determined as the test samples. The heavy metal levels were analyzed using standard solutions which were prepared within the same acid matrix. Standards for the instrument calibration were prepared on the basis of monoelement certified reference solution ICP Standard (Merck, Germany) (Yesudhason et al. 2013; Nkpaa et al. 2016).

Sample processing

The edible part of the samples was carefully removed from its shell and oven dried thoroughly using Memmert drying oven (U27, Germany) for 3 days at a temperature of 60–70°C, after which it was ground to powder form using Silimic mortar (Pyrex). Five grams of the sample was weighed into a crucible container, and then introduced into a furnace to derive the ash at 450–500°C for 6 h. Six hours later, a crucible thug was used to bring down the crucible from the furnace and placed in a desiccator where it was allowed to cool. After cooling, 5 mL of 10% hydrochloric acid was used to dissolve ash content to near dryness. After that, it was filtered into a funnel and cylinder before it was made up to 20 mL with distilled water before the metals analysis using atomic ASS (Nkpaa et al. 2013, 2016).

Atomic absorption spectrophotometer

ASS (model pm ver 2.02 Avanta) methods were used for each metal and was calibrated using standard of the metals (As, Cr, Ni, Cd, Pb and Fe). Cr, Fe, and As were evaluated using hollow cathode lamp (HCL) in a Flame atomizer AAS. Cd, Pb, and Ni were analyzed using electrode less discharge lamp (EDL) in the Flame atomizer AAS (Nkpaa et al. 2013, 2016). The extract was aspirated directly into the ASS machine. The carrier gas was acetylene and air pressure at of 70 psi.

Health risk assessment for shellfish consumption

Estimated daily intake (EDI)

Hazardous heavy metals exposure pathway to human via ingestion of polluted food has been investigated by many researchers (Copat et al. 2012; Xue et al. 2012; Chary et al. 2008; Nkpaa et al. 2016). EDI of individual hazardous metals in this study was evaluated by the equation below:

$$\mathrm{EDI} = \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{FIR} \times \mathrm{Cm}}{\mathrm{Wab} \times \mathrm{Ta}},$$

where EDI is the estimated daily intake; EF is the exposure frequency (365 days^{-1} year^{-1}); ED is the exposure duration, equivalent to average lifetime (65 years for Nigeria population); FIR is the fresh food ingestion rate (g^{-1} $person^{-1}$ day^{-1}), which was considered to be 102 g^{-1} $person^{-1}$ day^{-1} for fish consumers from Bodo City and B-Dere, Ogoniland, Rivers State, Nigeria (Nkpaa et al. 2016); Cm is the heavy metal concentration in foodstuffs (mg kg^{-1} Dw.) Conversion factor of 0.208 was used to multiply the Cm from fresh weight (FW) to dry weight (Dw.); Wab is the average body weight (bw) (Wab was considered to be 60 kg); TA is the average exposure time for non-carcinogens (equal to EF × ED) (Saha and Zaman 2012).

Target hazard quotients (THQs)

Estimation of human health risk via consumption of hazardous metals polluted shellfish was done using THQ. This was calculated based on the formula provided on USEPA Region III Risk-Based Concentration Table (USEPA 2011). The THQ is an estimate of the risk level (non-carcinogenic) due to pollutant exposure (Yu-Jun et al. 2011). If the ratio is equal to or greater than 1, an exposed population experiences health risks. The methods used for the estimation of THQ have been provided in USEPA Region III Risk-Based Concentration Table, January–June 1996 (Han et al. 1998; USEPA 2011; Chien et al. 2002; USDOE 2011). Given below is the equation used for THQs:

$$\mathrm{THQ} = \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{FIR} \times \mathrm{Cm} \times \mathrm{Ta}}{\mathrm{RfDo} \times \mathrm{Wab}} \times 10^{-3},$$

where THQ is the target hazard quotient; RfD is the oral reference dose (mg^{-1} kg^{-1} day^{-1}). RfD for Cr, Cd, Pb, As, Ni, and Fe are 1.5, 1E−3, 3.5E−3, 2E−2, 3E−4 and 1.7 mg^{-1} kg^{-1} day^{-1}, respectively (USEPA 2000).

Carcinogenic risk (CR)

USEPA stated that the Carcinogenic Risk between 10–6 (1 in 1,000,000) to 10–4 (1 in 10,000) represent a range of permissible predicted lifetime risks for carcinogens (Valberg et al. 1996; USEPA 2011). Chemicals for which the risk factor falls below 10–6 may be eliminated from further consideration as chemicals of concern (Liu et al. 2006). The human health risk associated with the carcinogenic effect of hazardous heavy metal is expressed as the probability that an individual may contract cancer over a lifetime period of 70 years (Liu et al. 2006; USEPA 2011; Nkpaa et al. 2016). The equation used for estimating CR was as follows:

$$\mathrm{CR} = \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{FIR} \times \mathrm{Cm} \times \mathrm{CSF}}{\mathrm{Wab} \times \mathrm{Ta}} \times 10^{-3},$$

where CR is the carcinogenic risk; CSF is the ingestion cancer slope factors. The ingestion cancer slope factors (CSF) evaluates the probability of an individual contracting cancer from oral exposure to pollutants over a period of a lifetime (ATSDR 2010; Nkpaa et al. 2016). Ingestion cancer slope factors for Cr, Cd, Pb, As, and Ni are 0.5, 0.35, 8.5E−3, 1.7, and 1.5 and are expressed in units of $(mg/kg/day)^{-1}$.

Statistical analysis

The data were statistically analyzed by SPSS software version 20. One-way ANOVA were applied for evaluating the significant difference between hazardous metals concentration in seafood, and student t-*test* was applied to evaluate the statistical differences between the two sites.

Results and discussion

The result for Cr, Cd, Pb, As, Ni, and Fe in shellfish sampled in Bodo City and B-Dere Ogoniland are presented on Table 1 with the following ranges: 1.84–4.49, 0.96–3.82, 1.64–3.67, 2.13–4.89, 4.35–8.34, and 1256.2–2593 mg kg^{-1} for Cr, Cd, Pb, As, Ni, and Fe respectively. The level of Cr in *T. facustus* from Bodo City and B-Dere was significantly ($p < 0.05$) higher than those of other shellfish. It can be seen that the level Cd, Pb, and As in *U. tangeri* from Bodo City and B-Dere was significantly ($p < 0.05$) higher than those of other shellfish. *C. gasar* from Bodo City and B-Dere had Ni mean level higher than those from the other shellfish. But there was no statistically significant difference in the mean level of Fe in all the shellfish analyzed. The result indicates the ability of *U. tangeri* to concentrate Cd, Pb, and As (2.54–3.82, 3.42–3.67 and 3.76–4.89 mg kg^{-1} for Cd, Pb, and As respectively) is much stronger than that of other shellfish. Therefore, the potential risk of consuming *U. tangeri* is relatively higher than that of other seafood due to the high Cd, Pb, and As bioaccumulation of *U. tangeri*. Because of high tolerance of shellfish to high level of Cr, Cd, Pb, As, Ni, and Fe, it may not affect the populace directly, but may subsequently transfer toxicity to humans through the food chain and render people consuming the shellfish more prone to contamination (Okazaki and Panietz 1981; Oliver 1997; Han and Hung 1990). This is because in most cases, these shellfish live in an environment with heavy metal contaminations. The FAO, WHO, EU, and other regulatory bodies of many countries have provided the maximum permissible limit of heavy metals in foods (Xue et al. 2012; Chary et al. 2008). The level of each metals determined in this study was above the maximum permissible limit by USEPA (2011). For example, Pb exceeded the permissible limit of 0.3 mg kg^{-1}, while Cd also exceeded maximum tolerable of 2 mg kg^{-1} by (EU 2006). However, Cr was above the minimum permissible limit of 1 mg kg^{-1} set by USEPA (2011). From the results, it can be predicted that

Table 1 Heavy metals levels (mg kg^{-1}) in shellfish from Bodo City and B-Dere, Ogoniland, Rivers State, Nigeria

Heavy metals	Sites	Shellfish				
		C. pallidus	*T. fucastus*	*U. tangeri*	*C. gasar*	Permissible limits
Cr	Bodo City	1.84 ± 0.42^{a}	4.49 ± 1.09^{b}	2.57 ± 1.24^{b}	3.46 ± 0.08^{b}	1.0
	B-Dere	$2.76 \pm 0.02^{a\#}$	3.97 ± 0.23^{b}	2.23 ± 0.12^{b}	2.76 ± 0.04^{a}	1.0
Cd	Bodo City	0.96 ± 0.63^{a}	1.43 ± 0.05^{b}	3.82 ± 0.08^{b}	1.20 ± 0.03^{a}	2.0
	B-Dere	$1.54 \pm 0.03^{a\#}$	2.12 ± 0.02^{a}	$2.54 \pm 0.01^{b\#}$	1.46 ± 0.02^{a}	2.0
Pb	Bodo City	2.12 ± 0.12^{a}	$3.12 \pm 0.09^{b\#}$	3.67 ± 0.22^{b}	2.28 ± 0.05^{a}	0.3
	B-Dere	$1.68 \pm 0.02_{a}$	2.56 ± 0.05^{a}	3.42 ± 0.14^{b}	1.64 ± 0.06^{a}	0.3
As	Bodo City	2.13 ± 0.02^{a}	2.67 ± 0.11^{a}	4.89 ± 0.03^{b}	2.36 ± 0.06^{a}	0.1
	B-Dere	2.73 ± 0.05^{a}	2.45 ± 0.02^{a}	3.76 ± 0.07^{b}	2.97 ± 0.02^{a}	0.1
Ni	Bodo City	$4.35 \pm 0.06^{a\#}$	$8.24 \pm 1.03^{b\#}$	6.67 ± 0.09^{b}	8.23 ± 0.14^{b}	0.5
	B-Dere	5.28 ± 0.03^{a}	5.98 ± 0.65^{a}	$8.34 \pm 0.05^{b\#}$	7.56 ± 0.06^{b}	0.5
Fe	Bodo City	1768.6 ± 5.11^{a}	2257.6 ± 1.67^{b}	$1868.2 \pm 2.86^{a\#}$	2074.0 ± 3.69^{b}	100
	B-Dere	$2593.2 \pm 2.48^{a\#}$	2004.6 ± 3.58^{b}	1256.2 ± 4.79^{b}	2468.0 ± 6.68^{a}	100

Value are expressed as Mean ± SEM of three replicates ($n = 5$). Across rows or down the columns, values with different alphabets are significantly different at ($p < 0.05$). Permissible limit of heavy metals in this table are from CXS 2013; USFDA 1993; FAO 1983; FAO/WHO 1989; Mokhtar 2009

[a]Not significantly different when each species are compared to each other (across rows)

[b]Significantly different when each species are compared to each other (across rows)

[#]Significantly different when each species are compared to each other (down the column)

consumption of shellfish from the Bodo City and B-Dere by humans can lead to chronic heavy metals poisoning.

Human health risk assessment

The results of EDI for shellfish are shown in Table 2. The EDI of Cr from consumption of these shellfish ranged between 0.65 and 1.59 g $person^{-1}$ day^{-1} with the highest intake of Cr coming from the consumption of *T. fucastus* collected from Bodo City (1.59 g^{-1} $person^{-1}$ day). This value is above the tolerable daily intake level (1.5 g^{-1} $person^{-1}$ day) established by FAO/WHO (1993) and USEPA (2011). EDI of Cr through the consumption of seafood from these study sites could adversely affect balanced glucose metabolism in the population. Chromium has been reported to facilitate insulin action (Nielsen 1993; Vincent 1999; Nkpaa et al. 2016). The EDI for Cd ranged between 0.34 and 1.35 g^{-1} $person^{-1}$ day. *U. tangeri from* Bodo City showed the highest EDI of 1.35 g^{-1} $person^{-1}$ day^{-1} for Cd and exceeded the tolerable daily intake of 0.001 g^{-1} $person^{-1}$ day^{-1} established by USEPA (2011) by 1350 times. The high EDI recorded for Cd in shellfish is an indication that it might lead to severe ingestion of Cd. Cd has been shown to cause acute and chronic intoxications by Chakraborty et al. (2013). If Cd is ingested in higher amounts, it may result to stomach irritation, vomiting and diarrhea. Over long-term exposure, Cd can become deposited in the renal tissues and finally lead to kidney disease, lung damage, and fragile bones (Bernard 2008; Jaishankar et al. 2014). Ingestion of high levels of Cd has been

Table 2 Estimated daily intake (EDI) (g^{-1} $person^{-1}$ day) of heavy metals via consumption shellfish from Bodo City and B-Dere, Ogoniland, Rivers State, Nigeria

Sites	Shellfish	Heavy metals					
		Cr	Cd	Pb	As	Ni	Fe
Bodo City	*C. pallidus*	0.65	0.34	0.74	0.75	1.54	625.2
	T. facustus	1.59	0.51	1.10	0.94	2.91	798.1
	U. tangeri	0.91	1.35	1.30	1.73	2.36	660.5
	C. gasar	1.22	0.42	0.81	0.83	2.91	733.4
B-Dere	*C. pallidus*	0.98	0.54	0.59	0.97	1.87	916.9
	T. fucastus	1.40	0.74	0.91	0.87	2.11	708.6
	U. tangeri	0.79	0.90	1.21	1.33	2.95	444.2
	C. gasar	0.98	0.52	0.58	1.05	2.67	872.7

reported to cause acute renal failure in humans (NANS-NRC 1982). Cadmium is a well-known endocrine disruptor capable of increasing the risk of developing prostate cancer and breast cancer in humans (Saha and Zaman 2012; Akoto et al. 2014).

Results also showed that EDI of Pb ranges between 0.58 and 1.30 g^{-1} $person^{-1}$ day, with *U. tangeri* collected from Bodo City having the highest EDI value of 1.30 g^{-1} $person^{-1}$ day^{-1}. This EDI value far exceeds the established EDI of Pb by USEPA (2011). Ingestion of Pb via the consumption of shellfish may cause chronic Pb intoxication in adults. It may also result in anemia, some types of cancer, and reproductive malfunction in males, while in young children, it may lead to hormonal imbalance of metabolite of vitamin D (1, 25- dihydroxy-vitamin D) and a drop in IQ (Tandon et al. 2001; Siddiqui et al. 2002; Lindbohm et al. 1991). Chronic lead exposure can also result in mental retardation, birth defects, psychosis, autism, allergies, dyslexia, weight loss, hyperactivity, paralysis, muscular weakness, brain damage, kidney damage, and may even cause death (Martin and Griswold 2009). The EDI of As and Ni ranged between 0.75 and 1.73 and 1.54–2.95 g^{-1} $person^{-1}$ day^{-1}, respectively, with the highest As and Ni intake coming from the consumption of *U. tangeri* collected from Bodo City and U. tangeri from B-Dere, respectively. The provisional tolerable intake for As is 0.0012 g^{-1} $person^{-1}$ day^{-1} USEPA (2011). *U. tangeri from* B-Dere showed the highest EDI of 2.95 g^{-1} $person^{-1}$ day^{-1} for Ni which exceeded the tolerable daily intake of 0.0012 g^{-1} $person^{-1}$ day^{-1} established by USEPA (2011) by 2458 times. Arsenic may cause protoplastic poison since it affects primarily the sulphydryl group of cells causing malfunctioning of cell respiration, cell enzymes, and mitosis (Gordon and Quastel 1948; Jaishankar et al. 2014). High levels of Nickel observed in this study could cause some genetic abnormalities like DNA strand break, DNA–protein cross links, nucleotide excision, micronuclei, nucleic acid concentration alteration, single gene mutations, sister chromatid exchanges, and cell transformation (Coogan et al. 1989; Das and Dasgupta 2000). Das and Dasgupta (2002) also reported decreased sperm count, sperm motility, alteration of steroidogenesis, suppresses antioxidant enzymes activities, and elevated testicular lipid peroxidation in nickel exposed rats (Gupta et al. 2007). EDI values of Fe ranged between 444.2 and 916.9 g^{-1} $person^{-1}$ day^{-1}. EDI rates of 916.9 g^{-1} $person^{-1}$ day^{-1} was obtained from the consumption of *C. pallidus* from B-Dere. The high level of Fe through the consumption of shellfish may be good sources of Fe in diets of consumers (Nkpaa et al. 2016). At the same time, it may be highly dangerous since too high levels can lead to intracellular breakdown and promote DNA damage (Jaishankar et al. 2014). Fe can also initiate cancer mainly by the process of oxidation of DNA molecules (Bhasin et al. 2002; Jaishankar et al. 2014).

We also calculated the THQs with RfD set by EFSA (2009, 2010) for Cr, Cd, Pb, As, Ni and Fe. THQs results indicate that there is no carcinogenic risk via consumption of shellfish as shown on Table 3. Values of the THQ index for total exposure above 1.0 indicate that the estimated exposure is potentially of concern. However, the THQ does not define a dose–response relationship, and its numerical value should not be regarded as a direct estimate of risk (USEPA 1996; Nkpaa et al. 2016). The THQs for Cr and Cd ranged from 04.30E−4–1.06E−3 and 0.34–1.35. However, the THQ value for Pb, As, Ni and Fe ranged between 0.17 and 0.37, 2.50–5.77, 0.08–0.15, and 0.63–1.25, respectively, with *U. tangeri* collected from Bodo City showing the highest THQ of 5.77. The THQs result indicated that Cr, Cd, Pb, and Ni were below the safe standard of 1. This observation is suggestive that consumers of seafood from the study sites would not experience significant health risks from intake of individual metals through seafood consumption, except for As and Fe which was above safe standard of 1 (Nkpaa et al. 2016). However, *U. tangeri* from Bodo City was above 1 for Cr. THQs values below 1 indicate that the level of exposure metal pollution is smaller than the reference dose (Copat et al. 2012). Therefore we can assume that the daily intake shown by results at this stage is

Table 3 Target hazard quotients (THQ) of heavy metals via consumption of shellfish from Bodo City and B-Dere, Ogoniland, Rivers State, Nigeria

Sites	Shellfish	Heavy metals					
		Cr	Cd	Pb	As	Ni	Fe
Bodo City	*C. pallidus*	4.30E−4	0.34	0.21	2.50	0.08	0.89
	T. facustus	1.06E−3	0.51	0.31	3.13	0.15	1.14
	U. tangeri	6.07E−4	1.35	0.37	5.77	0.12	0.94
	C. gasar	8.13E−4	0.42	0.25	2.77	0.15	1.05
B-Dere							
	C. pallidus	6.53E−4	0.54	0.17	3.23	0.09	1.13
	T. fucastus	9.33E−4	0.74	0.26	2.90	0.11	1.01
	U. tangeri	5.27E−4	0.90	0.35	4.43	0.15	0.63
	C. gasar	6.53E−4	0.52	0.17	3.50	0.13	1.25

more likely to cause deleterious effects during a lifetime in humans from As and Fe toxicity. In other words, the reference dose is not a sharp division line between "'safe" and "unsafe" intakes. It is by no means certain that intakes at or below the references are risk-free or that intakes above it pose undue risks (Rodricks and Jackson 1992). Li et al. (2014), and Krishna et al. (2014) reported that high THQ value >1 indicate a potential health risk to human beings, especially consumers who reside in area with serious metal pollution.

The averages carcinogenic risk (CR) of Cr, Cd, Pb, As, and Ni via the consumption of shellfish are shown in Fig. 1. The average carcinogenic risk for Cr, Cd, Pb, As, and Ni ranged between 3.25E−4–7.95E−3, 1.29E−4–5.13E−4, 2.29E−6–1.11E−5, 1.13E−3–2.60E−3, and 2.63E−3–5.02E−3, respectively, with *T. facustus* collected from Bodo City showing the highest CR value of 7.95E−3. CR is measured and expressed as a probability of contracting cancer over a lifetime of 70 years. CR results indicated that the average CR value of cancer risk from Pb accumulation did not show carcinogenicity, this is in agreement with our earlier work (Nkpaa et al. 2016). However, in comparison with established guideline values, data from this study indicate that these shellfish (*C. pallidus, T. fucastus, U. tangeri*, and *C. gasar*) collected from Bodo City and B-Dere may not be safe for human consumption and as such consumers of these species of seafood have the increased probability of contracting cancer from As and Ni exposure over a lifetime period of 70 years or more in future.

Conclusion

Data from this study indicated that there are significant health risks associated with heavy metal mobility in runoff water and absorption by sediments and seafood during wet season and its consumption especially for consumers of shellfish. This may contribute significantly to the levels of contaminants (metals) that an exposed population are at risk to in addition to the direct crude oil spill in coastal waters as seen in B-Dere and Bodo City, in Gokana Local Government Area, Ogoniand, Rivers State, Nigeria. The shellfish analyzed reveal potentially toxic level of heavy metals if they enter the food chain. Data obtained on EDI, THQs, and CR indicate that the levels of heavy metals found in the sampled shellfish represent a very high risk to human health. In the light of the above findings, policy makers in government and regulatory bodies should strongly encourage crude oil producing companies to maintain and repair their oil production and transportation facilities on a regular basis; provide strict security to oil installation facilities; and educate the populace, especially the youths, in these coastal on the danger of bunkering and illegal artisanal refining activities. These actions will help prevent human health risks associated with hazardous heavy metals contamination.

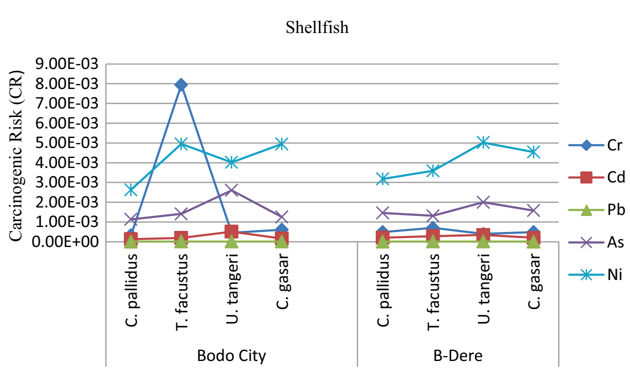

Fig. 1 Carcinogenic risks (CR) of heavy metals via consumption of shellfish from Bodo City and B-Dere, Ogoniland Rivers State, Nigeria

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