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Ecological Risk Assessment of Heavy Metals in Cassava Mill Effluents Contaminated Soil in a Rural Community in the Niger Delta Region of Nigeria

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Abstract This study evaluated the ecological risk assessment of heavy metals in cassava mill effluents contaminated soil in rural community in the Niger Delta region of Nigeria. Secondary data was used for the ecological risk assessment. Two background scenarios i.e. geometric mean (BGM) and median mean (BMM) was used as the reference value. The heavy metals that were assessed for ecological risk include viz: Cr, Zn, Cu, Co, Ni, Mn, Pb and Cd. 50% of mean detected individual heavy metals were considered for the location that was not detected. Assessment of the ecological risk was carried out following well established protocol. The results of the potential ecological risk (ER), Ecological risk index (ERI) and Monomial potential ecological risk (MPER) of heavy metals showed low risk under both scenarios except for Cd in one of the locations that showed moderate risk for MPER under both background scenarios in wet season. The distribution of the heavy metals based on potential ecological risk were in the order; Cd > Ni > = Pb > Co > Cu> Cr > Mn = Zn (BMM) and Cd > Pb > Ni = Co > Cu = Cr > Mn > Zn (BGM) for wet season and Cd > Pb = Ni = Cu > Co > Cr > Mn = Zn (BMM) and Cd > Pb > Cu = Co > Ni > Cr > Mn = Zn for dry season. The study showed low ecological risk associated with cassava mill discharged into the environment.
Keywords Cassava mill effluents; Contamination factor; Ecological risk index; Heavy metals

Background

Nigeria is the leading cassava producing country in the world, accounting for about 20% of total global production (Ohimain et al., 2013; Izah and Ohimain, 2015; Izah, 2016; Izah et al., 2017a; b; c; d; e; f). Cassava cultivation and processing is a major source of livelihood to several families in the southern Nigeria especially in the rural communities (Izah and Aigberua, 2017; Izah et al., 2017a; b; c; d). Cassava is processed by three scales of processor in Nigeria viz: smallholder, semi-mechanized and mechanized processing. But the small-scale processors have dominated the enterprise especially in the Niger Delta region of Nigeria. Rudimentary equipment is mostly used for processing of cassava tuber into *gari*, *lafun* and *fufu*.

During cassava processing, wastes are generated in different zones including peels from the peelings stage, cassava mill effluents from the dewatering/pressing zone and gaseous emissions from the frying stage (Ohimain et al., 2013). The liquid waste popularly known as cassava mill effluents is generated in the grating and dewatering zone and it account for about 16% of total weight of cassava tuber (Ohimain et al., 2013). The wastes are discharged into the environment without any form of treatment (Izah et al., 2017a; b). Thereby impacting on the characteristics of the receiving soil with regard to microbial, physicochemical cation and anions exchange, soil particle size, bulk density and porosity, heavy metals among others (Nwaugo et al., 2007, 2008; Ehiagbonare et al., 2009; Eneje and Ifenkwe, 2012; Nwakaudu et al., 2012; Osakwe, 2012; Okechi et al., 2012; Chinyere et al., 2013; Izonfuo et al., 2013; Omotiama et al., 2013; Ezeigbo et al., 2014; Ibe et al., 2014; Eze and Onyilide, 2015; Igbinosa, 2015; Igbinosa and Igiehon, 2015; Izah et al., 2017a; b; c; d; e; g; Omomowo et al., 2015).

One of the major constituent of the soil majorly impacted by wastes is heavy metals composition. Heavy metals concentration in soil is usually highest top most regions (Chen et al., 1997; Wei and Yang, 2010; Acosta et al., 2015; Mazurek et al., 2017) where the greatest bonding occurs (Parzych et al., 2012; Gu et al., 2016; Mazurek et al., 2017). Heavy metals are typically toxic when their concentration exceeds permissible level specified by appropriate agency in the biological system for the essential metals. While non-essential metals such as cadmium, mercury, lead, arsenic is highly toxic even at low concentration. Both essential and non-essential heavy metals have been detected in soil receiving cassava mill effluents (Nwakaudu et al., 2012; Osakwe, 2012; Igbinosa, 2015; Igbinosa and Igiehon, 2015; Izah et al., 2017c).

Authors have reported that heavy metals have density that is 5 times higher than the density of water (Idris et al., 2013; Hassaan et al., 2016; Izah and Angaye, 2016; Izah et al., 2016, 2017g). Their application in several domestic, industrial, agricultural and technological activities by humans have led to their increased distribution in the environment (Hassaan et al., 2016). Presently heavy metal is a major source of concern to human health and environment (Hassaan et al., 2016). This could be due to the toxic effect they pose in biological organisms and food chain. According to Hassaan et al. (2016), the toxicity of heavy metals relies on numerous criteria such as dose, method of exposure, and chemical constituent. In human system, it could cause several diseases which have been comprehensively documented by Izah et al. (2016, 2017h), Izah and Angaye (2016), Muhammad et al. (2014).

Again, industrialization, urbanization, developmental works and other anthropogenic activities are also having adverse impacts on the soil environment (Qiu, 2010). The soil plays several ecological, social purposes to human and other biodiversity (Izah et al., 2017c). Therefore, the occurrence of heavy metals in the soil especially the topmost part is one of the major concerns of environmentalists and public health practitioners (Mohseni-Bandpei et al., 2016).

In this regard, several environmental risk indices are used to assess the nature of the soil due to anthropogenic activities releasing heavy metals into the environment. Typically, ecological risk assessment associated with pollutant in the biophysical components of the environment (soil, air and aquatic ecosystems) and other environmental factors (such as chemical, physicochemical, biological, and eco-toxicological parameters) are often considered during environmental risk assessment (Fiori et al., 2013). The ecological importance of heavy metals in soil has attracted attention because of its close relation to human health especially in rural areas. One of the major parameters studied is the geochemical distributions of the environment (Jiang et al., 2014; Sofianska and Michailidis, 2016) including ground water (Bhutiani et al., 2017) and sediments (Hakanson, 1980; Zhu et al., 2012; Fiori et al., 2013; Ghaleno et al., 2015; Soliman et al., 2015; Todorova et al., 2016; El-Metwally et al., 2017) and soil (Yang et al., 2011; Al-Anbari et al., 2015). Therefore, risk assessment of heavy metals in the environment provides theory support for risk management (Zhu et al., 2012). Among the indices used in assessing risk assessment is contamination factor and potential ecological risk index (Mohseni-Bandpei et al., 2016) and they have widely applied in soil, sediment and water studies (Kowalska et al., 2016; Mazurek et al., 2017; Bhutiani et al., 2017).

Therefore this study focused on the ecological risk assessment of heavy metals in cassava mill effluent contaminated soil in rural community in the Niger Delta region of Nigeria with emphasis on the ecological risk (ER) and ecological risk index (R’). The findings of the study will useful to environmentalist and policy makers.

1 Materials and Methods

1.1 Study area

Ndemili lies between latitude N06º01’ and longitude E006º17’. Ndemili is one located in Ndokwa-West local government area of Delta state. Like other region of the state. It’s characterized by 28±6℃ and 50–95% of temperature and relative humidity respectively among both seasons (wet and dry) of the year. The average annual rainfall of 1900mm which is peculiar to other areas in Delta state (Orji and Egboka, 2015). Two predominant seasons include wet season (7 months-April to October) and dry season (5 months-November to March of the following year). But in recent times, it appears that season’s especially wet season beginning to shift from the conventional known period in the Niger Delta region of Nigeria. Farming of cassava, yam, maize, oil palm etc. is a major occupation of the indigenous people of the area (Izah et al., 2017c; e; g).

1.2 Data source

Secondary data was used for the assessment of the ecological risk of heavy metals in cassava mill effluents contaminated soil. Authors have recommended the use of geometric mean (Thambavani and Uma Mageswari, 2013; Bhutiani et al., 2017) and median mean (Monakhov et al., 2015; Bhutiani et al., 2017) as background values in assessment of environmental risk and it have been applied by Izah et al. (2017c; e; g). Hence, the background values including geometric mean (BGM) and median mean (BMM) was adopted in this study for the assessment of heavy metals level in 5 locations from cassava mill effluents contaminated soil analyzed in two predominant seasons (wet and dry) as reported by Izah et al. (2017c) (Table 1). Also contamination factor values previously reported by Izah et al. (2017e) (Table 2) was used for the study. The heavy metals considered in the study include Cr, Zn, Cu, Co, Ni, Mn, Pb and Cd.

Table 1 Concentration of heavy metals among the various locations with their respective background values

Seasons	Heavy Metals	Background considerations		Min	Max	Locations				
		BMM	BGM			LA	LB	LC	LD	LE
Dry	Cu	6.06	5.94	3.10	10.41	6.06	8.83	4.29	10.41	3.10
	Zn	43.45	32.47	9.65	49.75	9.65	38.09	43.45	45.41	49.75
	Mn	39.19	32.47	18.37	55.29	18.37	20.91	39.19	43.03	55.29
	Pb	5.27	4.84	1.66	10.63	9.92	10.63	5.27	2.88	1.66
	Cd	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	Cr	2.12	1.62	0.38	3.9	3.9	0.38	2.12	1.54	2.31
	Ni	2.66	2.85	1.88	4.21	4.21	1.88	2.66	4.20	2.13
	Co	10.31	8.13	3.34	11.28	3.34	10.31	11.28	10.86	8.39
Wet	Cu	3.87	4.07	3.34	4.84	3.87	4.83	3.69	3.34	4.84
	Zn	40.31	35.47	18.98	49.65	18.98	49.65	34.72	40.33	42.55
	Mn	39.69	35.82	18.47	53.87	18.47	53.87	34.07	43.83	39.69
	Pb	1.89	2.22	0.79	8.21	1.89	8.21	0.79	1.89	2.35
	Cd	0.23	0.3	0.23	0.479	0.23	0.479	0.23	0.23	0.447
	Cr	1.59	1.84	1.19	4.5	2.13	1.18	1.59	1.19	4.5
	Ni	1.38	1.77	0.88	4.87	0.88	2.94	4.87	1.38	1.00
	Co	0.039	0.051	0.039	0.083	0.083	0.039	0.039	0.039	0.071

Note: Izah et al. (2017c); BMM-Background median mean; BGM-Background geometric mean

Table 2 Contamination factor of heavy metals concentration in cassava mills effluent contaminated soil

Location	Seasons	BMM									BGM								
		Cu	Zn	Mn	Fe	Pb	Cd	Cr	Ni	Co	Cu	Zn	Mn	Fe	Pb	Cd	Cr	Ni	Co
LA	Dry	1.00	0.22	0.47	0.40	1.88	1.00	1.83	1.58	0.32	1.02	0.30	0.57	0.46	2.05	1.00	2.40	1.48	0.41
	Wet	1.00	0.47	0.47	0.92	1.00	1.00	1.34	0.64	2.13	0.95	0.54	0.52	0.90	0.85	0.77	1.58	0.50	1.63
LB	Dry	1.46	0.88	0.53	0.52	2.02	1.00	0.18	0.71	1.00	1.49	1.17	0.64	0.59	2.20	1.00	0.23	0.66	1.27
	Wet	1.25	1.23	1.36	0.80	4.34	2.09	0.74	2.13	1.00	1.19	1.40	1.50	0.78	3.70	1.60	0.64	1.66	0.76
LC	Dry	0.71	1.00	1.00	1.62	1.00	1.00	1.00	1.00	1.09	0.72	1.34	1.21	1.85	1.09	1.00	1.31	0.93	1.39
	Wet	0.95	0.86	0.86	1.26	0.42	1.00	1.00	3.53	1.00	0.91	0.98	0.95	1.23	0.36	0.77	0.84	2.75	0.76
LD	Dry	1.72	1.05	1.10	1.53	0.55	1.00	0.73	1.57	1.05	1.75	1.40	1.33	1.75	0.60	1.00	0.95	1.47	1.34
	Wet	0.86	1.00	1.10	1.21	1.00	1.00	0.75	1.00	1.00	0.82	1.14	1.22	1.19	0.85	0.77	0.65	0.78	0.76
LE	Dry	0.51	1.14	1.41	1.00	0.31	1.00	1.09	0.80	0.81	0.52	1.53	1.70	1.14	0.34	1.00	1.43	0.75	1.03
	Wet	1.25	1.06	1.00	1.00	1.24	1.96	2.82	0.72	1.82	1.19	1.20	1.11	0.98	1.06	1.50	2.44	0.56	1.39

Note: CF < 1 (low contamination); $1 \leq$ CF <3 (moderate contamination); $3 \leq$ CF < 6 (considerable contamination); CF ≥ 6 (very high contamination); Source: Izah et al. (2017e); BMM-Background median mean; BGM-Background geometric mean

1.3 Ecological risk index

Ecological risk index (ERI) is used to assess the ecological risk level of heavy metals in the environment (Hakanson 1980; Bhutiani et al., 2017) that could be toxic to biota (Yisa et al. 2012; Bhutiani et al., 2017). The Potential ecological risk (ER) is the index for individual metals, while the summation of ER is often expressed as R' (Singovszka et al., 2014). Based on the values presented in Table 1 and Table 2, the resultant ecological risk index was calculated and the result was compared to the criteria presented in Table 3. The formula for the calculation of both ER and R' has been previously presented by Hakanson (1980) and have been widely applied by Bhutiani et al. (2017), Singovszka et al. (2014), Soliman et al. (2015), Ghaleno et al. (2015), Todorova et al. (2016), Fiori et al. (2013), Karydas et al. (2015), Zhu et al. (2012), Qingjie et al. (2008), Elias et al. (2014), Qiu (2010), Mohseni-Bandpei et al. (2016), Swarnalatha et al. (2013), Tang et al. (2014), Vowotor et al. (2014), Mazurek et al. (2017), Kowalska et al. (2016), Gasiorek et al. (2017).

Table 3 Ecological risk index used to assess environmental pollution of cassava mill effluents contaminated soil

Risk	Low risk	Moderate risk	Considerable risk	High risk	Very high/Extreme risk
Ecological risk (ER)	Er <40	Er 40 ≤ Er <80	80 ≤ Er<160	160 ≤ Er <320	Er ≥ 320
Ecological risk Index (R')	R'<150	150≤ R'<300	300≤ R'<600	-	R'≥ 600
Monomial potential ecological risk (MPER)	MPER ≤ 50	50 < MPER ≤ 100	100 < MPER ≤ 150	150 < MPER ≤ 200	MPER > 200

Note: ER and R' was developed by Hakanson (1980) and have been widely applied by Bhutiani et al. (2017), Singovszka et al. (2014), Soliman et al. (2015), Todorova et al. (2016), Fiori et al. (2013), Karydas et al. (2015), Zhu et al. (2012), While MPER was modified from Hakanson (1980) by Guan et al. (2014)

ER = Tr x CF (Equ 1)

Where Tr is the toxic response factor viz: Cr = 2, Pb = Cu =5, Cd = 30 and Zn = 1 (Hakanson, 1980), Ni = 5 (Xu et al., 2008; Soliman et al., 2015; Bhutiani et al., 2017), Co = 5 (Swarnalatha et al., 2013) and Mn = 1 (Xu et al., 2008; Soliman et al., 2015) and CF represents the contamination factor (Table 2).

$$R' = \sum ER_{Cu} + ER_{Mn} + ER_{Co} + ER_{Ni} + ER_{Cd} + ER_{Cr} + ER_{Zn} + ER_{Pb} \text{ (Equ 2)}$$

Modified (Monomial) potential ecological risk

Monomial potential ecological risk (MPER) is one of the modified risk indices used to assess and or/ identify sensitivity of the heavy metal contamination in an environment i.e. soil. MPER is calculated by summing up products of the concentration of all the heavy metal and their respective toxic factor and divided by the background values. MPER have been calculated by Guan et al. (2014) as:

$$MPER = \sum \frac{(TxC_{cu})+(TxC_{Mn})+(TxC_{Co})+(TxC_{Ni})+(TxC_{Cd})+(TxC_{Cr})+(TxC_{Zn})+(TxC_{Pb})}{Bm} \text{ (Equ 3)}$$

Where T = Toxic factor; C = Concentration of individual metals; Bm = Background values

2 Results and Discussion

The potential ecological risk (ER) used to assess heavy metals in cassava mill contaminated soil is presented in Table 4. The risk index ranged from low (ER < 40) to moderate (Er 40 ⩽ Er < 80). In all the eight heavy metals assessed, the risk level was low in all the locations across both seasons except for cadmium. Cadmium concentration in wet season of both background considerations (BMM and BGM) was moderate. Furthermore, cadmium concentrations for wet season of LA under BGM scenario were also moderate. The high moderate risk of cadmium in wet season of some locations could be due to impact of runoff after rainfall and or/ other human activities in the mills. The values reported in this study had some similarity with the work of Soliman et al. (2015) who reported uncontaminated sediment from Mediterranean coast of Egypt by lead, zinc and copper. Again the higher cadmium concentration in the ecological risk is comparable to the findings of Fiori et al. (2013) on aquatic pollution control in coastal water bodies from Rio de Janeiro state, Brazil. Zhu et al. (2012) reported that cadmium has higher ecological risk compared to other metals. The higher ecological risk of cadmium could be due to the higher toxic factor (Zhu et al., 2012; Ghaleno et al., 2015). The trend of cadmium having higher ecological risk is also comparable to the work of Todorova et al. (2016) that reported heavy metals in sediment of a small hydropower cascade in the order; mercury > cadmium > arsenic ~ copper > lead > zinc. Cadmium which has no known biological function is relatively higher and it's toxic to biodiversity including plants, animals even at low concentration (Ghaleno et al., 2015; Izah et al., 2016). Furthermore, Zhang and Shan (2008), Ghaleno et al. (2015), Sayadi et al. (2015a, b), Sayadi and Sayyed (2011) also reported that cadmium is mainly from anthropogenic sources and are affected mostly by human interference.

Table 4 Potential ecological risk (ER) of heavy metals in cassava mill effluents contaminated soil

Location	Season	BMM									BGM								
		Cu	Zn	Mn	Fe	Pb	Cd	Cr	Ni	Co	Cu	Zn	Mn	Fe	Pb	Cd	Cr	Ni	Co
LA	Dry	5.00	0.22	0.47	-	9.40	30.00	3.66	7.90	1.60	5.10	0.30	0.57	-	11.25	30.00	4.80	7.40	2.05
	Wet	5.00	0.47	0.47	-	5.00	30.00	2.68	3.20	10.65	4.75	0.54	0.52	-	4.25	23.10	3.16	2.50	8.15
LB	Dry	7.30	0.88	0.53	-	10.00	30.00	0.36	3.55	5.00	7.45	1.17	0.64	-	11.00	30.00	0.46	3.30	6.35
	Wet	6.25	1.23	1.36	-	21.70	6.07	1.48	10.65	5.00	5.95	1.40	1.50	-	18.50	48.00	1.28	4.98	3.80
LC	Dry	3.55	1.00	1.00	-	5.00	30.00	2.00	5.00	5.45	3.60	1.34	1.21	-	5.45	30.00	2.62	4.65	6.95
	Wet	4.75	0.86	0.86	-	2.10	30.00	2.00	17.65	5.00	4.55	0.98	0.95	-	1.80	23.10	1.68	13.75	3.80
LD	Dry	8.60	1.10	1.10	-	2.75	30.00	1.46	7.85	5.25	8.75	1.40	1.33	-	3.00	30.00	1.90	7.35	6.70
	Wet	4.30	1.10	1.10	-	5.00	30.00	1.50	5.00	5.00	4.10	1.14	1.22	-	4.25	23.10	1.30	3.90	3.80
LE	Dry	2.55	1.41	1.41	-	1.55	30.00	2.18	4.00	4.05	2.60	1.53	1.70	-	1.70	30.00	2.86	2.25	5.15
	Wet	6.25	1.06	1.00	-	6.20	58.8	5.64	3.60	3.60	5.95	1.20	1.00	-	5.30	45.00	4.88	2.80	6.95

Note: Er < 40 (Low risk); Er 40 ⩽ Er < 80 (Moderate risk); 80 ⩽ Er < 160 (Considerable); 160 ⩽ Er < 320 (High); Er ⩾ 320 (Very high)
BMM-Background median mean; BGM-Background geometric mean

Figure 1 present the makeup of the potential ecological risk index of the various metals under study. On the overall, cadmium > lead=nickel > cobalt > copper > chromium > zinc = manganese in wet season under BMM consideration and cadmium > lead = nickel = cobalt = copper > chromium > zinc = manganese in wet season under BGM scenario. In dry season, the ecological risk of the metals were in the order; cadmium > lead = nickel = copper > cobalt > chromium > zinc = manganese under BMM consideration and cadmium > lead > copper = cobalt > nickel > chromium > zinc = manganese under BGM consideration. The trend in this study is comparable to the work of Al-Anbari et al. (2015), who reported potential ecological risk of heavy metals in the order; cadmium > lead > nickel = cobalt > chromium = zinc is urban soil affected by anthropogenic activities.

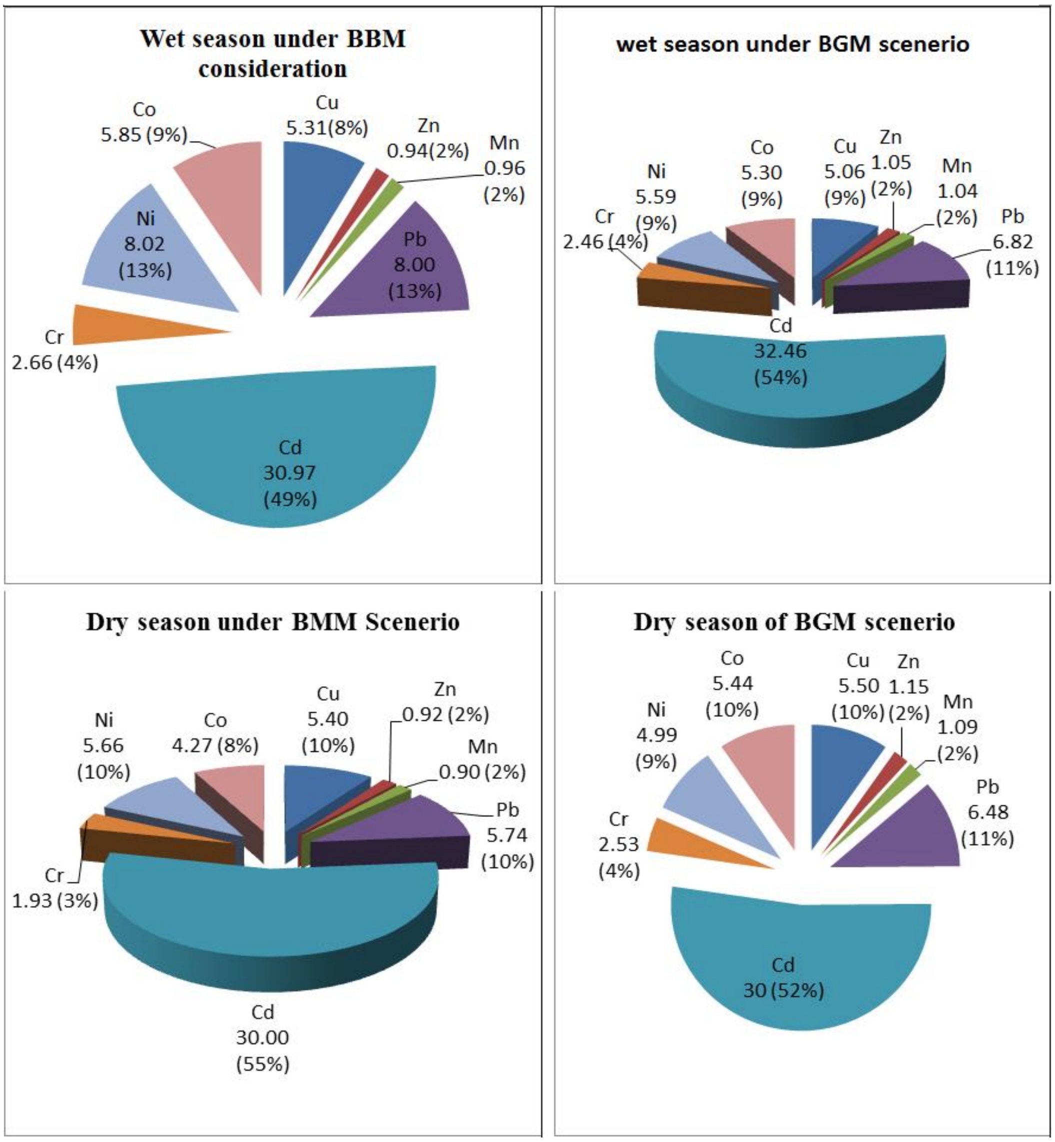

Figure 1 Makeup of the potential ecological risk index

Furthermore, the ecological risk index is presented in Figure 2. In both seasons and background scenarios, the ecological risk was generally low. The low ecological risk index shown in this study is comparable to trend previously reported by Bhutiani et al. (2017). Typically, the ecological risk showed variation in toxicity of the different heavy metals (Zhu et al., 2012; Fu et al., 2014; Todorova et al., 2016).

Table 5 presents the modified (Monomial) potential ecological risk of heavy metals from cassava mill effluents contaminated soil from a small-scale cassava processing mill in the Niger Delta region of Nigeria. The values for each of the heavy metals across the various sampling locations in both seasons (wet and dry) indicate low risk (MPER ⩽ 50) apart from cadmium in LE which showed moderate risk (50 < MPER ⩽ 100) under both background considerations in wet season. This is an indication of effect of season on soil contamination by cassava mill effluents. This trend suggests low ecological risk of the cassava mill effluents on soil quality.

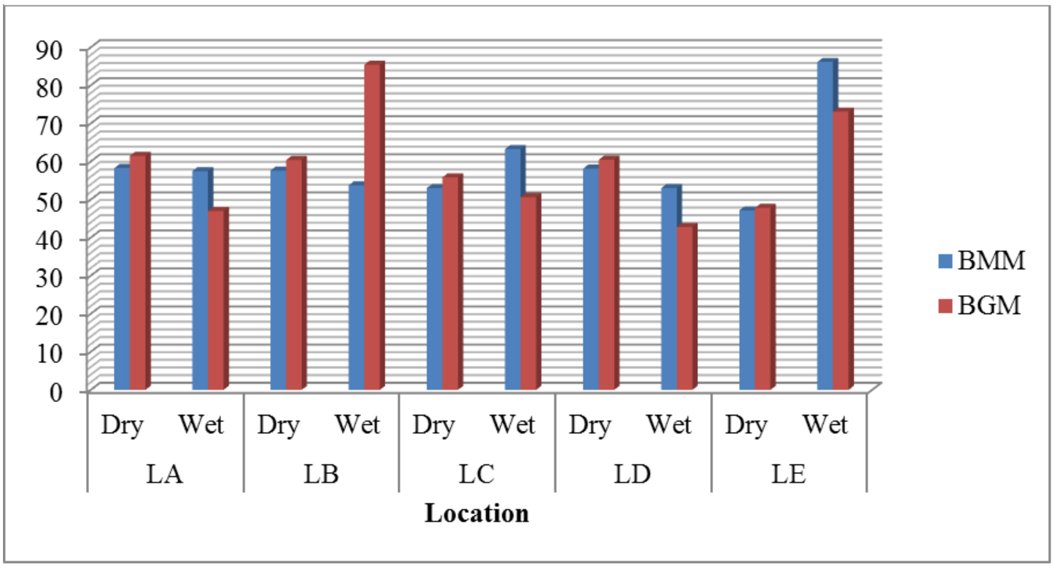

Figure 2 Ecological risk index (R') of heavy metals in cassava mill effluents contaminated soil
Note: R' <150 (Low risk); 150 ≤ R' < 300 (Moderate risk); 300 ≤ R' < 600 (Considerable); R' ≥ 600 (Very high)

Table 5 Modified (Monomial) potential ecological risk of heavy metals from cassava mille effluent contaminated soil

Seasons	Heavy metals	BMM					BGM				
		LA	LB	LC	LD	LE	LA	LB	LC	LD	LE
Wet	Cu	2.35	6.16	4.31	5.00	5.28	2.68	7.00	4.89	5.69	6.00
	Zn	0.47	1.36	0.86	1.10	1.00	0.52	1.50	0.95	1.22	1.11
	Mn	1.00	4.34	0.42	1.00	1.24	0.85	3.70	0.36	0.85	1.06
	Pb	5.00	10.43	5.00	5.00	9.78	3.83	8.00	3.83	3.85	7.50
	Cd	40.19	22.26	30.00	22.45	84.91	35.82	19.24	25.92	19.40	73.37
	Cr	1.25	4.32	7.06	2.00	1.45	0.99	3.37	5.50	1.56	1.13
	Ni	10.00	5.00	5.00	5.00	8.75	8.00	4.00	4.00	4.00	7.00
	Co	5.00	6.24	4.77	4.32	6.25	4.75	4.53	4.53	4.10	5.95
Dry	Cu	5.00	7.29	3.54	8.59	2.56	5.10	7.43	3.61	8.76	2.61
	Zn	0.22	0.88	1.00	1.05	1.14	0.30	1.17	1.34	1.40	1.53
	Mn	0.47	0.53	1.00	1.10	1.41	0.57	0.64	1.21	1.10	1.70
	Pb	9.41	10.09	5.00	2.73	1.47	10.25	10.98	5.44	2.98	1.60
	Cd	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
	Cr	3.68	0.36	2.00	1.45	2.18	4.81	0.47	2.62	1.90	2.85
	Ni	7.91	3.53	5.00	7.89	4.00	7.39	3.30	4.67	7.37	3.74
	Co	1.62	5.00	5.47	5.27	4.07	2.05	6.34	6.94	6.69	5.16

Note: MPER ≤ 50 (Low risk); 50 < MPER ≤ 100 (Moderate risk); 100 < MPER ≤ 150 (Considerable risk); 150 < MPER ≤ 200 (High risk); MPER > 200 (Very high/Extreme risk)

3 Conclusions

This study assessed the ecological risk assessment of heavy metals in cassava mill effluent contaminated soil in rural community in the Niger Delta region of Nigeria. The results of the ecological risk index of heavy metals (viz: Cr, Zn, Cu, Co, Ni, Mn, Pb and Cd) revealed that cassava mill effluents discharged into the environment by smallholder cassava processors in the Niger Delta had low ecological risk.

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