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Table of Content

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Full Length Research Paper

Community perception of heavy metal pollution and related risks in Lake Victoria Wetlands, Uganda

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Wetlands contributing a wide range of livelihoods to the riparian communities are progressively challenged with compounding heavy metals pollution. Controlling the negative impacts of the associated toxicants and adherence to policy implementation requires increased awareness among the local communities. This study investigated the socio-economic variables determining community risk perception of heavy metal pollution in the Lake Victoria wetlands associated with different land uses. A cross-sectional survey was conducted focusing on the wetlands' pollution status, sources and effects of toxicants on human health. Age, education and occupation were significant predictors of the community risk perception of the wetlands' heavy pollution. Individuals with at least secondary education were more likely to say a wetland was polluted or not. 68 % and 45 % of respondents agreed that industrial and commercial agricultural activities respectively, were the major sources of heavy metal pollution. Less than 25% of respondents identifying related implications of heavy metal contamination on human health was attributed to the low pollution risk awareness among the wetland dwellers. Therefore, there is a need to incorporate environmental pollution risk concepts at the different education levels using proper risk communication strategies to enable local communities to exploit wetlands resources from an informed point of view.

Key words: Community risk perception; heavy metal pollution; Lake Victoria wetlands.

INTRODUCTION

The release of heavy metal pollutants into the environment due to rapid population growth, industrialization, and agricultural technologies has posed a serious threat to human and wildlife health, as they are highly toxic, persistent, and capable of bioaccumulating in the various trophic levels of aquatic ecosystems (Ahmaed et al., 2016; Zaidi and Pal, 2017; Ali et al., 2019). The health hazards associated with this pollution have been known for ages, and the risks have been steadily increasing in many countries over the last century (Bhargava et al., 2017). This has led to increased research on food safety, specifically concerning health risks from the consumption of food contaminated with heavy metals (Mansour et al., 2009; Saha and Zaman, 2013). Recently, public health risks from exposure to intake of pollutants are now evident enough that the regulation topic due to the gradually higher values of toxic metals in the environment is very crucial (Ihedioha et al., 2016). In many developing countries where protein sources are limited, riparian communities depend on the wetland's fisheries for protein sources; however, these wetlands are increasingly contaminated with heavy

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metals pollution (Rahman et al., 2013), indicating a lack of awareness of the implications of such pollution to the among socio-economic factors that influence the heavy communicated to support local communities in making risk-based decisions established from a balanced judgment emerging from factual evidence about the imminent situation, their values and interests (Lahr and Kooistra, 2010). Earlier research done on the contamination of polychlorinated biphenyls pollution among the Rhone River inhabitants by Comby et al. (2014) revealed that many people got contaminated due to a lack of access to proper communication about the pollution level of the river. Thus, there is a need for effective risk communication involving the exchange of opinions and information between community members and institutions, discussing risk types and measures for dealing with risks (Lahr and Kooistra, 2010). To achieve this, it is important to apply coherent language to describe the magnitude of risk using scientific and policy perspectives to avoid public controversies (Leiss, 2004; Comby et al., 2014). Prior knowledge of community perception of pollution risk is important to consider before any formal communication exercise starts and this is influenced by many factors.

Geographical location, culture and many socio-economic factors influence community perception of environmental issues. But also, the mode of communication influences the outcome. Earlier studies have reported that community-related investigations (Jurg et al., 2009) and a person's exposure to the local pollution source (Grasmuck and Scholz, 2005) also influence local communities' responses to an environmental problem. Otherwise, a seemingly long-term environmental problem can turn into a pending disaster due to problem-damping and problem-amplifying with time and space by local communities with differing discourses (Comby et al., 2014).

Lake Victoria wetlands contribute considerably to rural income through the direct supply of ecosystem services. However, the wetlands are challenged with increased heavy metal pollution from different urban, industrial and commercial agriculture-associated activities (Bakyayita et al., 2019; Dietler et al., 2019). Recent assessment within Lake Victoria's Nakivubo channel recorded high levels of lead (Pb > 0.1 mg/L) and mercury (Hg > 0.01 mg/L) (Dietler et al., 2019). Other studies focusing on urban areas, particularly Kampala also confirm increased heavy metal pollution (Batbayar et al., 2017; Eliku and Leta, 2018; Zhen et al., 2016). Increased heavy metal contamination in wetlands has been postulated to result in negative health impacts on endangered communities with time (Abdel-Tawwab et al., 2017; Miebaka and Adiela, 2019). There is a need to effectively communicate with the wetland dwellers, based on how they perceive pollution aspects. The people's perceptions and attitudes are underlying factors influencing environmental management related decisions and an individual's behavior change is stimulated by these factors (Eck et al., 2019).

Therefore, this survey assessed the determinants among socio-economic factors that influence the heavy metal pollution risk perceptions of the wetland communities within the northern part of Lake Victoria. Based on the fact that as the contamination level differs substantially, the actual exposure and the associated potential risks will also vary in the different communities (Jiang et al., 2017). This wetlands community's perception of heavy metal pollution risk offers a foundation for the development of effective pollution risk communication approaches in the region.

MATERIALS AND METHODS

Study area

Situated along the equator at an elevation of approximately 1134 m a.s.l., Lake Victoria has many bays fringed with permanent wetlands, which are supported by its modified equatorial climate type with rainfall ranging from 1100 to 1600 mm occurring throughout the year. The riparian communities derive a wide range of livelihoods from these wetlands.

Indeed about 80% of the wetlands dwellers directly utilise the wetlands for food, household water and settlement (Kakuru et al., 2013). However, the increasing human populations, land uses and climatic variabilities are putting immense stress on the wetland resources, resulting in varying wetland pollution exposure levels. This study interviewed communities in different wetlands in the northern part of L. Victoria. Industrial wetlands were those highly affected by heavy metal pollution from urban and industrial activities within and neighbouring Kampala and Jinja cities (Batbayar et al., 2017; Dietler et al., 2019; Zhen et al., 2016), particularly Bulenga, Gabba, Mukono and Masese (Figure 1).

Agricultural wetlands were those associated with commercial agriculture, particularly Lutembe in Kampala, Lukaya in Mawokota and Wairaka in Kakira. And the natural wetland was Nabugabo wetland in Masaka due to the large coverage of intact natural wetland vegetation.

Survey design and tools

Data were collected with a cross-sectional design from adults living in the eight wetlands who had given consent to participate in the study. Everyone filled out a consent form which described the objectives of the study and the need for their consent to participate. The survey tool had questions for establishing the sources of heavy metal contamination and community risk perception of metal pollution within the wetlands. The questions included open-ended ones, some with categorical options of yes/no, multiple-choice ones, those with Likert scale (agree, do not know and disagree) and some with five–point ordinal scale options to measure the level of perception of pollution effect on the wetland water and general wetland system as exemplified in Table 1. The initial section of questions had the social and economic indicators adopted from Ondiek et al. (2020**)**, which included age, educational background, marital status and major occupation. Other social and economic factors included the location of the homestead in the wetlands, wetland fish species caught and the consumption of fish among others. A survey was also done to assess the possible recommendations for proper management of wetlands pollution. The number of households directly dependent on the wetlands for

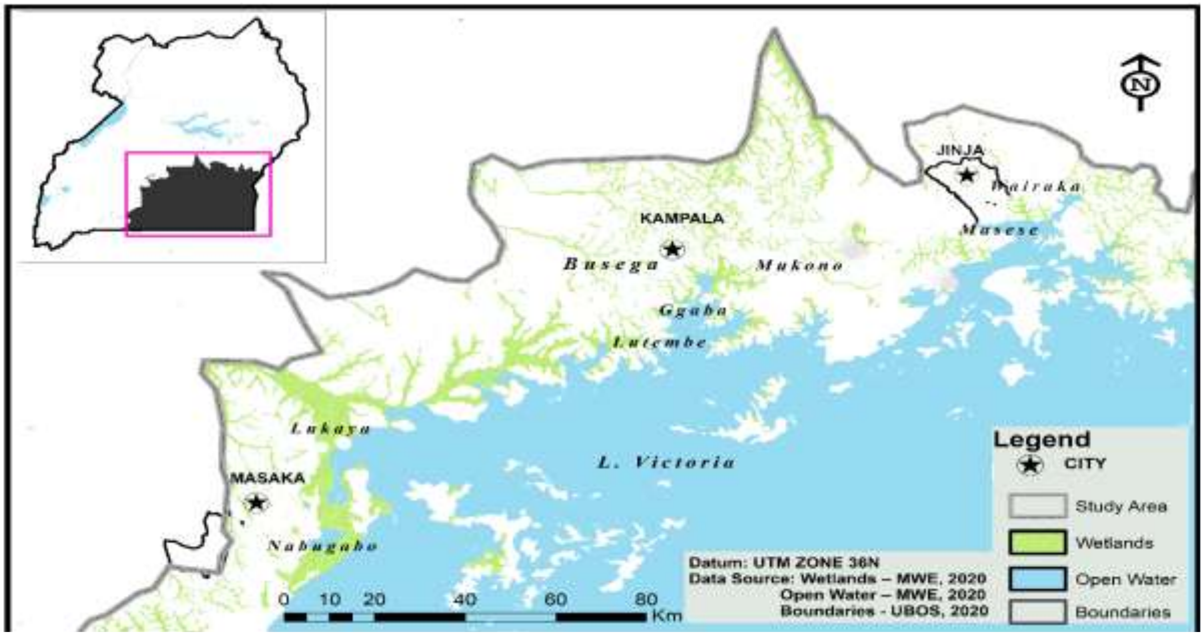

Figure 1. The different wetlands along the Lake Victoria shores.
Source: Authors

Table 1. Sample questions for community perception of heavy metal pollution risk.

Perception of heavy metal pollution problem, sources, and effects on wetland
Have you heard of heavy metal pollution in water bodies like wetlands, lakes, and rivers? (Yes, No, Don't know)
This land use activity ((industries, commercial agriculture, sand mining, fishing, and other activities) could be releasing heavy metal pollutants into the wetland. Do you…? (Agree, Do not know, Disagree)
How would you rate the effectiveness of these activities (industries, commercial agriculture, sand mining, fishing, and other activities) on the wetlands' structure and wetlands water quality? (5 - None/very low (None or not impacting on wetland); 4 - Low (Affect less than 25% of the wetland); 3 - Moderate (Affect 25-49% of the wetland); 2 - High (Affect 50-75% of the wetland); 1 - Very high (Dominate wetland (>75%)); 0 - Extreme (Totally dominated or affected by the land use activity)
Perception of heavy metal pollution risk
Do you use wetland water or eat wetland fish? (Yes, No)
Do you think heavy metal pollution affects fish? (Yes, No, Don't Know)
If yes, how do you think fish are affected by pollution? (habitat change/breeding, body physiology, migration to other areas, death, other, specify)
Do you think eating fish contaminated with heavy metal pollution may affect people's health? (Yes, No, Don't know)
If yes, could these (damage the kidneys, damage to the nervous system, skin cancer, liver damage, cause cancer, affect baby growth during pregnancy or affect brain development in children) be some of the effects? (Agree, Do not know, Disagree)

Source: Authors

agriculture, settlement, and water supply in the Lake Victoria wetlands was about 156,754 (UBOS, 2016).

Based on Krejcie and Morgen (1970) table of sample size, the target sample size for this study was 380 people at a 5% margin of error and 95% confidence interval. However, 313 valid qualitative data entries were made through face-to-face interviews using the questionnaire tool preloaded in the Kobo Collect application (CC-BY-NC-ND 4.0) installed on Android-based phones. Before the qualitative data collection, research assistants were trained for three days on the questionnaire tool and ethics. To ensure good quality data collection, the tool was designed with restrictions and skips to some questions. Pretesting of the tool was done and a satisfactory reliability check using Cronbach Alpha of 0.69 was attained. The key stakeholders including the wetlands farmers, fishermen, local community members, environment officers and local council chairpersons were interviewed.

Data analysis

Data were downloaded from the server into an excel sheet, cleaned, coded and then transferred to SPSS version 15 for statistical analysis. Then it was summarized using descriptive statistics to derive the means and proportions of the responses. A binary regression analysis was used to determine the major predictors for community risk perception on whether the wetland was polluted or not and whether urban/industrial activity highly impacted the wetlands. In this analysis, the socio-economic and other identified perceptions such as knowledge of where industries dispose of their waste, and heavy metal effect on human and fish health represented the independent variables (predictors). Wetland being polluted was regarded as a dependent binary variable, assigning a value of 1 to polluted wetlands if a respondent said yes and a value of 0 for no. All predictors were also converted to binary values first. Later binary regression analysis with further categorical variables was done to identify specific categories that were significantly predicting the community risk perception model.

RESULTS

Socio-economic trends of the wetland community

Among the respondents, 31% were females and 69% were males. The majority belonged to the 26 – 45 years age group specifically, 59% were within the age group of 26 - 35 years and 34% were young within the age range of 15 to 25 years. The rest were above 35 years of age. 57% of respondents were married. 43% never attended school and 48 % had attained at least a secondary school education. Regarding the location of their homestead, 19% lived within the wetland area, 51 % lived at a distance of 1 Km from the permanent wetland areas and the rest lived more than 1 Km away from the permanent wetland area. The major economic activities done by communities varied among the different wetland groups (Figure 2). However generally the dominant activities varied from fisherman (37%), farmer (26%), animal husbandry (10 %) and, other activities like motorcyclists, traders, cleaners, teachers, and hairdressers.

Wetland fishery characteristics

The majority (43%) of the wetland fishermen had a 2- to 5- year experience in fishing. 37% had less than 2 years of fishing experience and 20% had more than 5 years of fishing experience. These wetland fishermen were catching fish using nets and hooks (43%), hooks only (36%) baskets (18%) and a combination of all three (3%). Although some could use more than 100 hooks, the average number of hooks was 38 ± 33 in all wetlands. The fishermen mainly caught *Protopterus aethiopicus* and *Clarias gariepinus* and the small *Clarias* species (Nsonzi) in all wetlands. Other fish species caught from wetlands included Tilapia and Haplochromine species. Comparing the wetland categories; urban/industrial affected, commercial agriculture associated and natural wetland, there were differences in fish commonly caught (Figure 3). 54% of fishermen in urban/industrial associated wetlands caught *Protopterus* sp all year round and *Clarias gariepinus* mostly in the wet season. While the commercial agriculture and natural wetland groups, fishermen caught *Protopterus* sp and *Clarias* sp more all year round. This small-scale fishery catch contributed to their livelihoods, earning 9000 to 350,000 Ug. X per day's fishing catch depends on the season and on average they earn 55000 Ug. X per day (Table 2). Question regarding the changes in wetland fishery production, 83% agreed that there was a reduction in the fish caught over the years. 72% of the respondents noted that the caught fish size had reduced to mainly medium-sized ones. There were differences in response to the question of what could be causing the fish catch decline among individuals from different wetlands (Figure 4). 45 % of respondents from the natural wetlands agreed that agriculture is main cause of fish decline while 46 % of those from urban/industrial affected wetlands agreed that industries are the major cause of fish catch changes in the wetlands. Overall, fishing, agriculture and industries were the major contributors to wetlands' fish catch decline at the response percentage of 26, 32 and 29% respectively.

Community perception of heavy metal pollution risk

Comparing awareness of how different land uses impact the wetlands among respondents from different land use-affected wetlands, there were notable differences. In the urban/industrial-affected wetlands, 44% of respondents agreed that industries had an extreme impact, mining had less than 25% impact, and 32% of them agreed that fishing had less than 25% impact on the wetlands. In the commercial agriculture-affected wetlands, 55% of respondents agreed that agriculture had impacted the wetlands to a high level of 50 to 75%. Nearly 25% of respondents agreed that industries/factories had a significant impact on wetlands, while respondents from natural wetlands agreed that industries had a less than 25% impact and agriculture had a moderate impact (Figure 5). Mining had a significant impact on the wetlands, with up to 70% of the natural wetland being used for sand mining sites. Regarding the awareness of heavy metal pollution problem in the wetlands, 83% of individuals in urban/industrial affected wetlands were aware of this problem. Majority of the respondents from all the wetland stated that industries polluted by releasing waste in the wetlands while commercial agriculture pollute via the use of fertilizer and pesticides (Figure 6). The consumption of wetlands' fish and the possible effects on human health in case there was any heavy metal contamination in the fish was assessed. While 24% of respondent stated that they eat wetland fish, 47% agreed that they eat *Protopterus* sp fish at least once a month. Comparing individuals from different wetland groups, 86% of respondents from natural wetlands eat whole fish while those from other wetlands eat pieces, half fish and

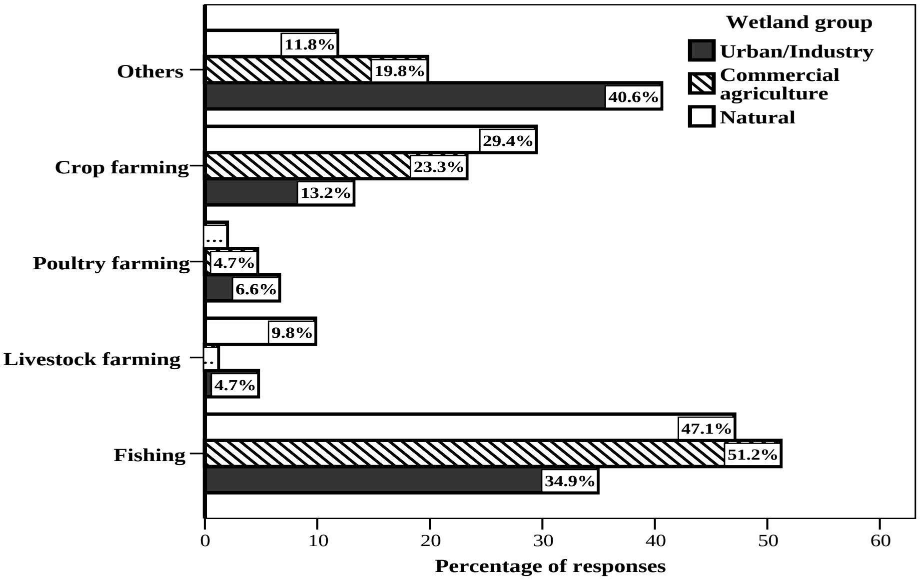

Figure 2. The major economic activities of the communities in the different.
Source: Authors

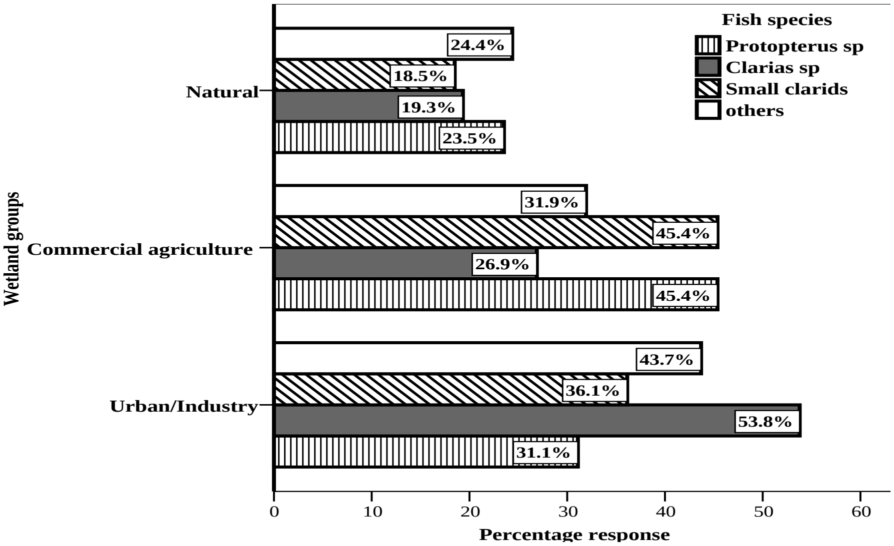

Figure 3. The dominant fish species caught from Lake Victoria wetlands.
Source: Authors

sometimes whole fish depending on availability and price. Many of the respondents agreed that fish get heavy metal contamination in the polluted wetlands (Figure 6). Despite that, 44 and 33% of respondents from urban/industrial and commercial agricultural affected wetlands, respectively, agreed that they eat fish from these wetlands (Figure 7). With respect to the question about the effect of consuming fish contaminated with heavy metals on human health, their responses varied a lot depending on which wetlands they were associated to. Generally, 71% agreed that this could affect human health (Table 3). But a low percentage of respondents could relate heavy metal contamination to specific human health issues. The identified health issues were kidneys dysfunction (27% of respondents), skin cancer (28%), liver damage (39%), cause other cancer types (26%) and effects on baby growth during pregnancy (22%). It was also realised that 75% of respondents perceived that even fish health can be affected by heavy metal pollution in the wetlands.

The binary linear regression for the perception that the wetland was polluted was performed. It revealed that six significant factors were influencing the opinion of the interviewed individuals (Table 4). These factors were

Table 2. Percentage responses on the wetland fishery (N = 115) and land use impact (N = 313) on the Lake Victoria wetlands.

Variable	Responses %		
Fish caught from the wetland	*Protopterus* sp	92	
	Clarias sp	72	
	Small clarids	29	
	Others	8	
Mean number of fishing gear (hooks) used per day		38 ± 33	
Average price of 1 kg of *Protopterus* sp (Ug. X)		7500 ± 4500	
Average price of 1 kg of *Clarias* sp (Ug. X)		6400 ± 2500	
Fishing income per day (Ug. X.)		55600 ± 9500	
	***Protopterus* sp**	**%**	**% *Clarias gariepinus***
Consumption of wetland fish	Everyday	2	13
	Twice a week	12	8
	Once a week	15	15
	Once a month	46	27
	N/A	24	37
To what extent has the quantity of fish caught changed?	Increased	4	
	Decreased	72	
	Same	5	
	Don't know	19	
Cause of the change in fish catch	Fishing	26	
	Agriculture	32	
	Mining	6	
	Industries	29	
	Others	7	
	Don’t know	5	

Source: Authors

age, education, occupation, wetland, best fishing season and knowledge of where industries dispose of their waste. Using the odds ratio values, it was three times ($p = 0.003$) more likely that respondents in one age group would consider that a particular wetland was more severely polluted than another age group. From further regression of age categories, the 15 to 25 years age group was the only significant category at $p = 0.021$ and these respondents were most likely to respond that a wetland was polluted. Regarding education, it was two times more likely that respondents in one education category would say that a wetland was polluted than those in another education category. On further regression of the education level categories, the secondary school category was the only significant ($p = 0.003$) category. Therefore, those with secondary education were more likely to say that wetlands were polluted than those with other education categories. The occupation was also a significant predictor at $p = 0.006$ and further categorical analysis identified that respondents with other occupations which included motorcyclists, traders, cleaners, teachers, and others were more likely to say that a wetland was polluted. The wetland location variable was also a significant predictor and it was further realised that respondents from Wairaka, Masese, Bulenga and Lukaya were more likely to say that the wetland was polluted all at $p < 0.05$. The knowledge of where the industries disposed of their waste was also a significant predictor.

Those who responded that industries disposed of waste in the wetlands, were more likely at $p < 0.05$ to say that wetlands were polluted than those who responded differently.

An open question tool was used to gather potential management options to ensure proper management of heavy metal pollution and four major categories of possible options to improve heavy metal waste management within the wetlands were identified (Table 5). Implementation of environmental laws and land use management was highly suggested with about 28% of respondents. Strict environmental monitoring and sensitization were also suggested. 37% suggested that government should have restrictions on industries and farming within the wetland and ensure regular monitoring

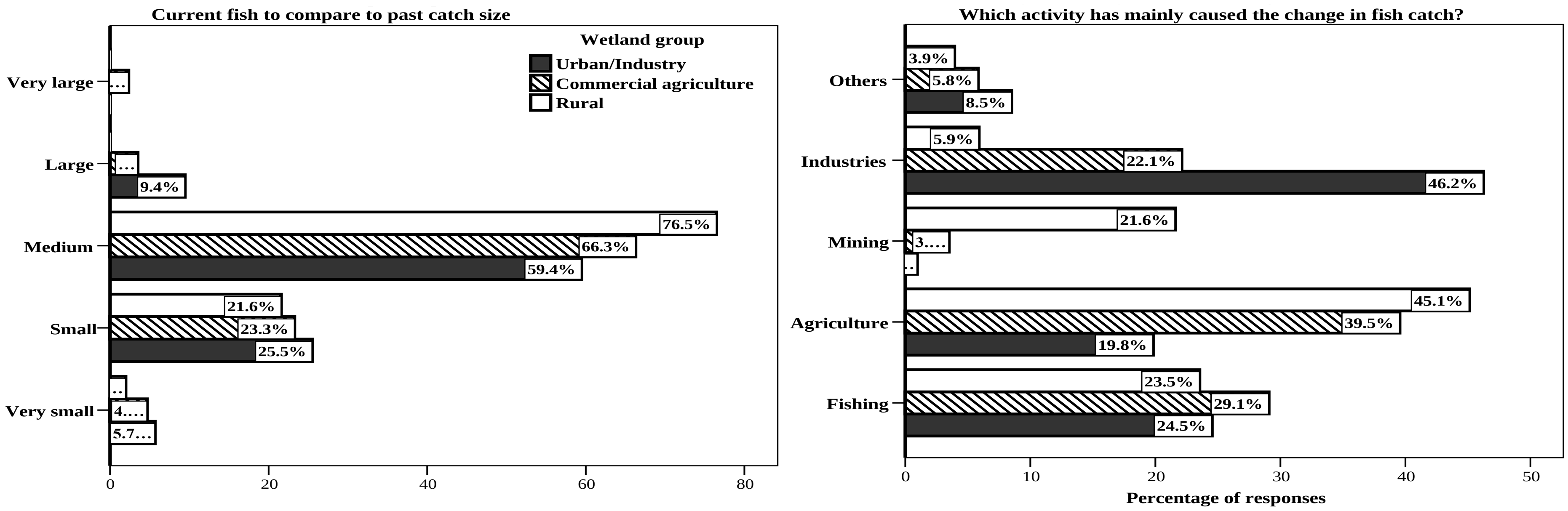

Figure 4. The community perception of the current fish sizes and what land use activity has mainly caused the changes in fish catch (N=115).
Source: Authors

of industrial activities. They also suggested that there should be proper disposal of wastes, monitoring of the extent of pollutants toxicity, relocation of polluting industries and commercial farmers dealing in floriculture from wetlands. Government should put more effort in sensitising wetlands dwellers on how to sustainably use the wetland.

DISCUSSION

This study focused mainly on examining the community perception of heavy metal pollution concerning the socio-economic characteristics of the wetland dwellers considering the spatial variation of the wetlands. It was realised that age group, educational background, occupation and the particular wetland where one lives were important determinants of one's response to whether a wetland was polluted or not. Pollution risk perception is a general belief derived from a variety of risk attitudes and conclusions determined by the characteristics of different citizen groups (Grasmuck and Scholz, 2005). Respondents in the 15 – 25 years age group and those with secondary education were more likely to say that a wetland was polluted based on what they observed in their surroundings. This compares with the research done in Kenya by Egondi et al. (2013) who realised that individuals who perceived higher levels of air pollution had at least a primary education level unlike those with no or less than a primary education level. Therefore, the knowledge attained in a particular level of education of respondents could have enabled them to spot the basic characteristics of a polluted area. According to Jurg et al. (2009), there is a general observation that educated people are more concerned about environmental pollution. Therefore, formal education could have increased their understanding of the characteristics of a polluted and non-polluted wetland and could even suggest the main source of pollution in their locality. The occupation was also a significant predictor that respondents with other occupations such as motorcyclists, traders, cleaners, teachers and others were likely to say

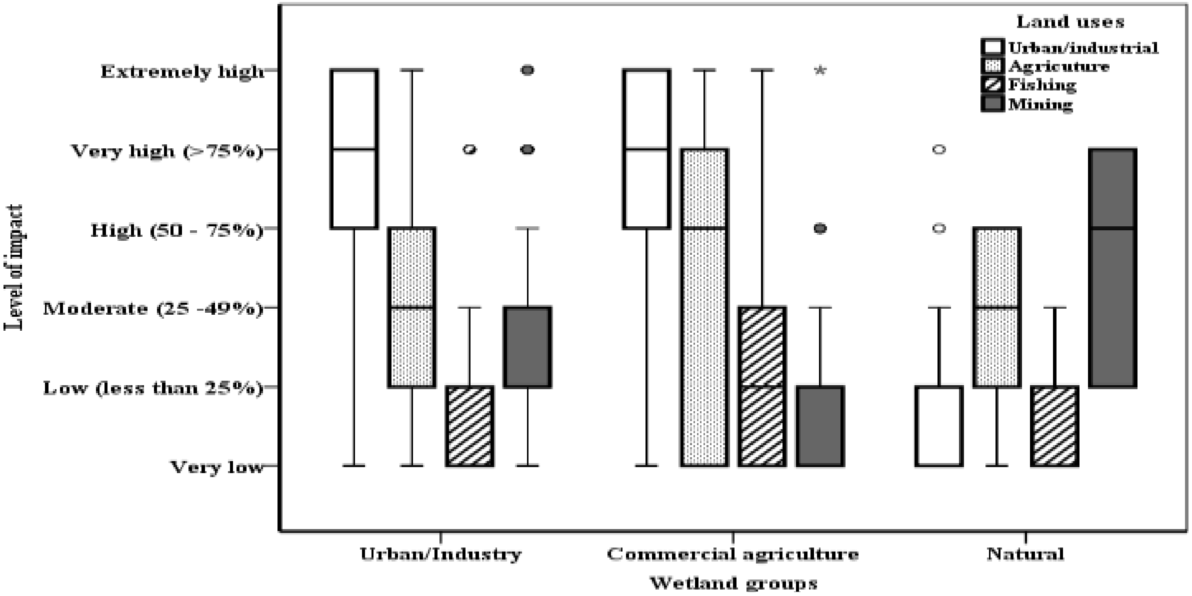

Figure 5. Wetland communities' perception of the impact of different land uses on the wetland (N = 313).
Source: Authors

that a wetland was polluted. It have been reported that the involvement in different kinds of occupation by respondents associated significantly with the varying perception of pollution (Egondi et al., 2013).

The exposure to better environments could have influenced the respondents with other occupations to say that the wetlands were polluted. The type of risk (voluntary or involuntary imposed risks, known or unknown risks); social dimensions and individual behavioral and personality attitudes towards the hazards are some of the factors that influence the community pollution risk perception (Lahr and Kooistra, 2010).

There were different responses about the sources of wetland pollution among individuals from different wetlands. For instance, those engaged in fishery-related activities reported that industry substantially impacted wetlands and this was attributed to their belief that their fishing activity had a less negative impact on the wetlands. According to Comby et al. (2014), the response gathered depended on the oral history (personal thoughts about the pollution causes and consequences) and life history (his whole life experiences). On the other hand, a high percentage of respondents agreed that industries were major polluters and that industries released their waste into the wetlands. This was attributed to their education level which ensured that they could characterize the effects of industrial activities on the environment. But many respondents also hinted on acquiring information from different media. Mass media such as newspapers, radio and TV are recognized as sources of information about pollution, influencing citizen perspectives (Cisneros and Schweizer, 2018).

More respondents from the natural wetland agreed to eating wetland fish than those from other wetlands. The determinant factors like availability and low prices of fish, the perception of fish as a healthy and nutritious food and limited protein alternatives, increase the consumption rate of fish (Ilibezova et al., 2013). Fish was readily available in the natural wetlands and respondent considered it good for consumption. Since large natural water resources are ecologically active that the pollution dilution capacity is high (Sarkar and Das, 2022). This background could have encouraged those with environment management awareness to consume the fish from natural wetland without reservations. People living in urban/industrial affected wetlands consumed less fish and this was attributed low acceptability of fish coming from the visibly polluted wetlands. In many developing economies, the pollution from industries and municipal uses result in various problems like poor waste disposal and cases of stagnating polluted waters in the environment (Zaidi and Pal, 2017). These sights directly discourage people in their right minds from eating fish coming from the nearby wetlands. There were differences in fish size consumed among the wetland groups. This was attributed to the variation in the fish prices, that any increased prices lead to low capita fish consumption (Ilibezova et al., 2013). Fish prices in urban areas were high which could have led to consumption of pieces of fish rather whole fish.

Environmental exposure to heavy metal pollution posed serious health threats to human well-being because these metals interfere with the basic metabolic processes leading to fatal diseases among humans (Bhargava et al., 2017).

Metal bioaccumulation by fish also affects the long-term

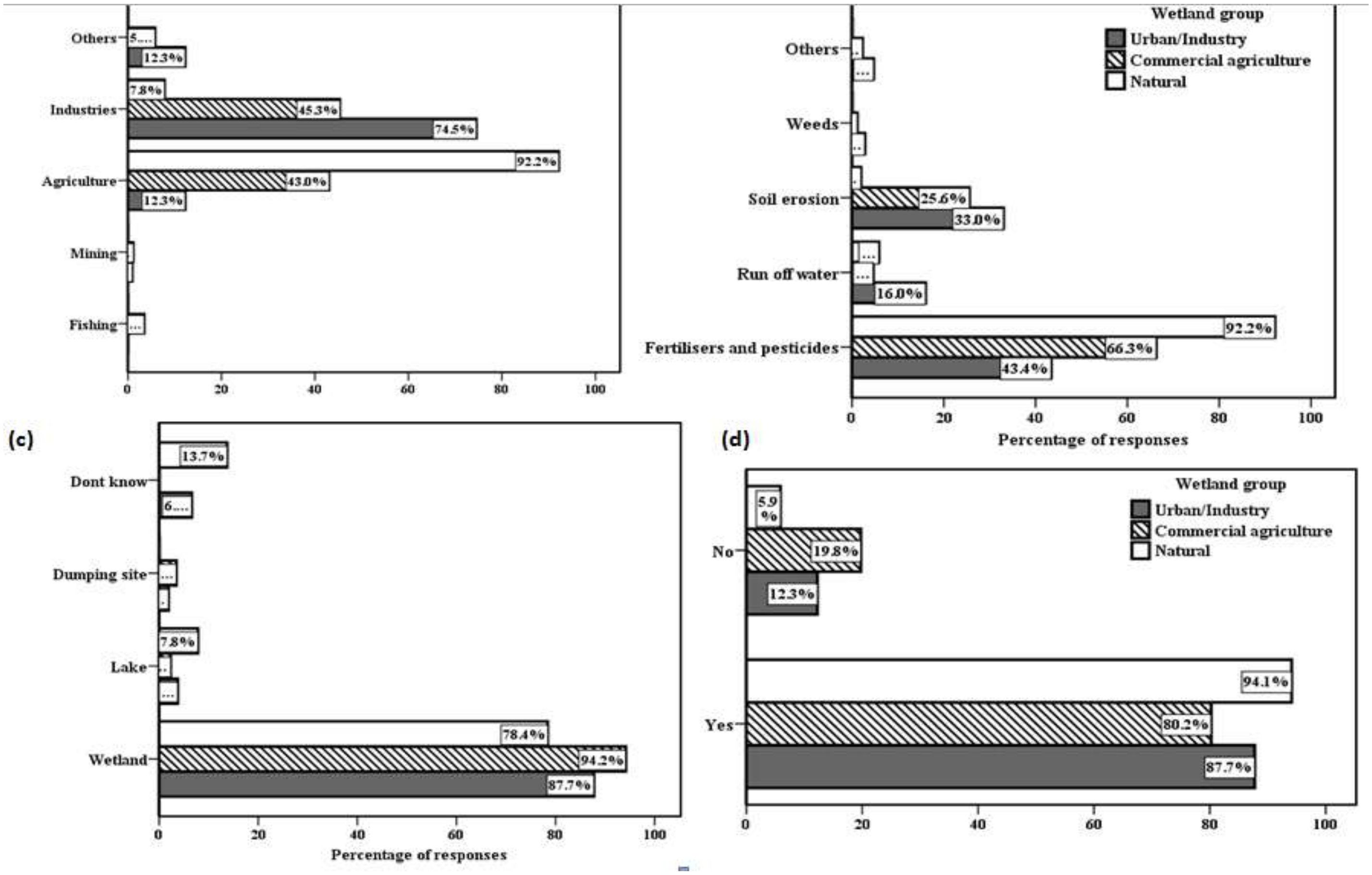

Figure 6. Awareness of Heavy metal pollution: (a) the dominant land use releasing heavy metals in the wetlands is. (b) commercial agricultural activities are affecting the wetlands through ... (c) industrial activities affect wetlands by releasing wastes in … and (d) do you think fish can get heavy metal contamination in these wetlands?
Source: Authors

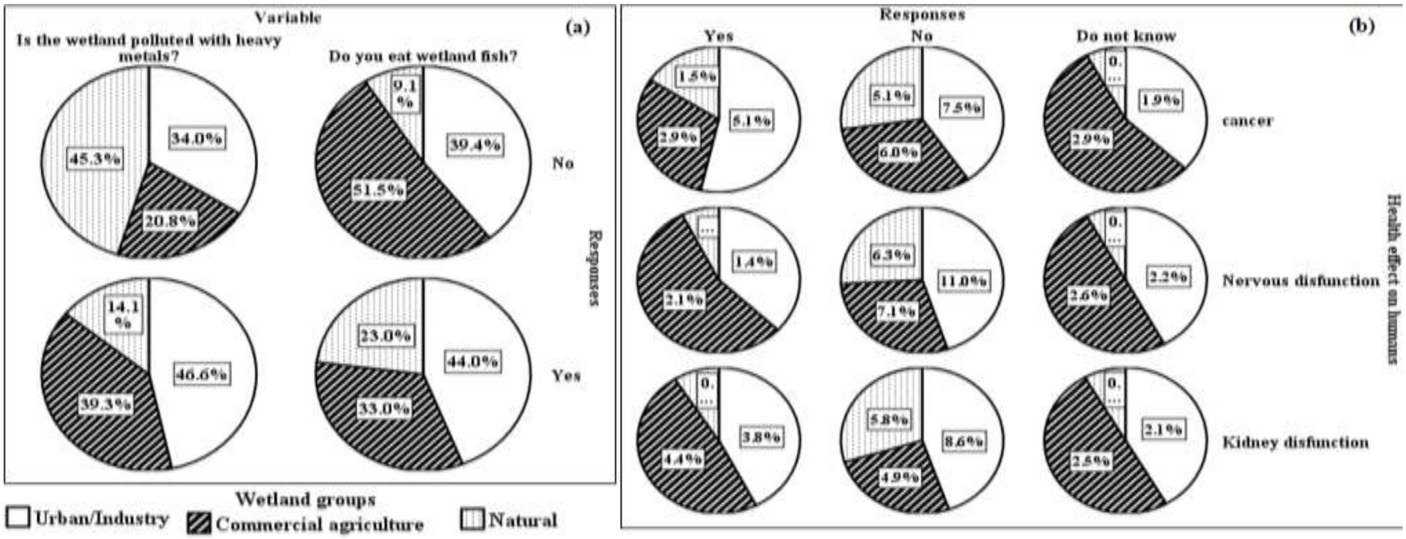

Figure 7. Community perception of whether wetlands are polluted with heavy metals (a) and the effects of eating contaminated fish over time to the human health (b) among responded from different wetlands groups.
Source: Authors

Table 3. Wetlands' heavy metal pollution sources and effects on the human and fish health perceptions (N=313).

Subject		% Response		
		Agree	Do not know	Disagree
Eating fish contaminated with heavy metals can affect people's health.		71	16	13
Land use activity mainly releasing heavy metals into the wetlands	Fishing	5	70	25
	Agriculture	45	45	10
	Mining	23	70	7
	Industries	68	31	1
	Other activities such as	5	86	9
Heavy metal pollution effect on human health	Damage to Kidney	27	15	58
	Damage to the nervous system	11	16	73
	Skin cancer	28	16	56
	Liver damage	39	14	47
	Cause cancer	26	15	59
	Affect baby growth during pregnancy	22	14	64
	Affect brain development in children	10	17	73
Do you think heavy metal pollution affects fish?		75	15	10
Heavy metal pollution effect on fish health	Change breeding habitat	62	28	10
	Body physiology	13	75	11
	Migrate to other areas	23	64	13
	Death	61	29	10
	Others, specify (reduced size and number of eggs)	4	83	16

Source: Authors

Table 4. Predictors on the perception of polluted wetlands and if urban/industrial activities highly impact wetlands.

Perception model	Predictors	B	*p*	Odds ratios
Wetland is polluted	Age	1.070	0.003	2.916
	Education	0.561	0.028	1.753
	Occupation	0.352	0.006	1.422
	Distance of homestead from wetland	0.506	0.096	1.658
	Sources of Income	-0.173	0.312	0.841
	Wetland location	-1.204	0.000	0.300
	Best fishing season for wetland fish	0.042	0.026	1.043
	Industrial disposal of waste knowledge	0.890	0.001	0.411
	Constant (intercept)	-2.624	0.006	0.073
Urban/industries were highly impacting wetlands	Age	0.293	0.475	1.340
	Education	0.022	0.930	1.022
	Occupation	0.321	0.041	1.005
	Wetland location	-0.722	0.000	0.486
	Distance of homestead	-0.772	0.077	0.462
	Sources of Income	-0.509	0.147	0.601
	Constant	1.119	0.012	3.712

Source: Authors

Table 5. Responses about potential management options to reduce heavy metal pollution in the wetlands (N=313).

Suggestions category	Emphasized suggestions
Implementation of environmental laws	Restrictions on industries and farming activities in the wetlands Ban the use of illegal fishing gear Gazette for wetland buffer zones Reduce corruption among law enforcers Strengthen punishments for wetlands management law violators
Strict monitoring of activities	Develop teams through responsible ministries to monitor activities of industries in terms of disposal of their wastes, the extent of waste toxicity, nature of the water quality and wetlands' fishery, and emerging land use within the wetlands
Improve waste management	Create garbage sites away from wetlands for industrial and other human activity waste Reclaim the wetland cover and detoxify wetland areas Construct latrines for the wetland dwellers Ensure that industries have proper waste management
Land use management	Relocate industries and commercial farming activities from wetlands Gazette-specific areas for industries away from wetlands Stop licensing industrial activities in the wetlands
Sensitization	Sensitize wetlands dwellers on how to sustainably use the wetland Increase awareness and empower fishermen to use better fishing methods Wetlands people reduce the consumption of food or fish coming from contaminated areas.

Source: Authors

fish physiology leading to early death and a reduction in their reproduction capacity (Bawuro et al., 2018). In this study, it has been found that individuals were aware of the negative effects of pollutants on the wetlands; given the high percentage response that heavy metal contamination can affect human well-being. However, a few could relate heavy metal contamination to specific health issues in humans and fish.

According to Grasmuck and Scholz (2005), individual pollution risk perception and acceptance are greatly determined by the person's exposure (or not) to the local pollution hazard source. Many respondents could have had insufficient knowledge of the heavy metal potential risk to human well-being from personal experience or any other sources. Of those who were able to suggest specific health issues, not even one of them scored a higher percentage response than others. Such inconsistencies demonstrated that rather than actual knowledge, it is self-estimated knowledge from which they decided the effect of metal pollution on human well-being. Actually, because of problem-damping and problem-amplifying with time and space, different local communities have varying discourses of the same pollution (Comby et al., 2014). The low knowledge of the effects of heavy metal contamination on people's and fish health among the community members was attributed to limited risk communication to the wetland dwellers. The wetlands communities' responses about the specific risk were limited to the distorted information that reached them from the different sources. Moore (2016), states that what complicates environmental pollution risk communication is the quality of the information passed on to the public media due to exaggeration for a dramatic effect. Therefore, national-level strategies should be developed for environmental risk communication and should be based on appropriate risk communication principles that ensure the sources and effects of heavy metal risk contaminants on biodiversity and human health are effectively communicated (Ramírez et al., 2019).

Pollution risk perception depends on risk communication which is also based involvement of community members and policymakers (Lahr and Kooistra, 2010). Local community leaders and other players many times fail to convey the risks and any other important information with an adequate approach (Grasmuck and Scholz, 2005). This impairs the understanding of risks and larger acquiescence of management options mutually agreed upon. With a good foundation, the involvement of the local communities in the development of capacity for the management steers the ultimate sustainable exploitation of natural resources (Utsala, 2013). The sustainable well-being of L. Victoria wetland dwellers with respect to heavy pollution depends on the establishment of a good pollution risk communication policy before specific pollution preventions are developed. While communicating the risks, appropriate communication skills are important and the disseminator should be perceived as a trustworthy and responsible person (Lahr and Kooistra, 2010).

In addition, to other means, media plays a fundamental role in the information exchange between the public, science and policy, inspiring prompt adoption of pollution guidelines at the local, regional or national level.

Different countries have utilized a variety of means at policy and public levels to prevent and treat metal harmfulness arising from environmental influences, accidents and occupational exposure (Bhargava et al., 2017). For instance, banning the use of certain pesticides and agrochemicals, and developing more effective wastewater treatment means that reduce the metal pollution content in the wetlands (Ustaoğlu et al., 2020). There is a need to have wetland fish consumption advisory based on a comprehensive information base ranging from what fish eat and fish species' exposure to heavy metal pollution. For instance, to control fish mercury pollution and reduce human mercury exposure due to contaminated fish consumption, a complete set of information about mercury pollution in different fish species and health risks associated with fish consumption was made available to enable the public to make responsible decisions needed (Boischio and Henshel, 2000). The use of appropriate communication measures ensure that all community members are reached using expert knowledge in a layman’s understanding to guard against misunderstanding (Lahr and Kooistra, 2010).

Based on the clear relationship between education and risk perception, there is also a need to enhance the curriculum at different levels of education in the country concepts. Community education programmes to increase awareness of sources of heavy metal pollution and their related risks can also alleviate low-risk communication. A comprehensive heavy metal mitigation plan should be developed that takes into consideration the local communities' perceptions of the environmental pollution risk problem and devises actions that promote sustainable use of wetlands. There should be a Wetlands Resources Advisory to operate risk communication programmes among the exposed population due to the consumption of contaminated fish from the wetlands.

Conclusion

The major determinants of community perception of heavy metal pollution risk were age group, education background and livelihood activities which were attributed to the impact of these parameters and their influence on people’s concern with environmental problems. Education was a significant predictor of community perception and this emphasized the need to enhance the curriculum with environmental pollution and risk perception concepts at the different education levels, including community environmental communication programmes to increase awareness of heavy metal pollution problems and their related risks. The limited knowledge of any specific implications of heavy metal on human and fish health was an indicator of low pollution risk communication among wetland dwellers. Therefore, as monitoring of pollutants for control continues, there is a need to develop strategies for national environmental policy on pollution risk communication using appropriate and effective communication means about heavy metal pollution in the wetlands.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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Full Length Research Paper

Contamination level of spent engine oil in the rhizosphere of *Arachis Hypogea* L.

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One of the prevalent soil contaminants in Nigeria is spent engine oil (SEO). This experiment aimed to evaluate how spent engine oil affected various heavy metals and mineral composition in the rhizosphere of *Arachis hypogaea* L. Concentrations of 0 (control), 100, 200 and 300 ml of SEO were used to pollute soil bags containing *A. hypogaea* plants, respectively. In the Botanic Garden of the University of Nigeria, Nsukka, they were put up in 9 repetitions in a completely randomized manner. The soil was tested for heavy metals and mineral components after three months of contamination. In a dose-dependent manner, the data revealed a significant (P 0.05) rise in pH, organic matter, and carbon. The concentrations of lead, zinc and iron increased drastically as the concentration of SEO increased, from 0.57 in the control to 1.89 with 300 ml effluent for lead, 1.66 to 1.73 (iron) and 0.95 to 1.48 mg/kg (zinc) according to heavy metal analyses. SEO application did not negatively alter soil texture, but it did greatly improve soil cation exchange capacity, nitrogen, accessible phosphorus, and other mineral nutrients, according to the study. In conclusion, despite heavy metal deposition, the groundnut plant's rhizosphere action may have improved the mineral contents of the soil. However, more research is needed to determine the metal uptake by the plant and its potential use in phytoremediation.

Key words: *Arachis hypogaea,* environmental pollution; heavy metals; phytoremediation; spent engine oil.

INTRODUCTION

With an ever-increasing human population comes a rise in the demand for energy for transportation, residential, and industrial purposes. Since the 1950s, petroleum-based (fossil) fuels have been the primary source of energy (Ismail et al., 2014). Increased usage of petroleum and its derivatives, such as gasoline, diesel, and motor lubricants, has resulted in significant soil degradation around the world, as well as greenhouse gas emissions that contribute to climate change (Nowak et al., 2019). In both industrialized and developing countries, the environmental impact of petroleum exploration, production, refining, and transportation are a serious problem (Okieimen and Okieimen, 2005). Spent engine oil (SEO) is a petrochemical that has been identified as large and widespread soil contamination in Nigeria (Sharifi et al., 2007).

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After servicing and draining used oil from vehicles and generator engines, SEO is obtained. It includes heavy metals and potentially hazardous polycyclic aromatic hydrocarbons (Sharifi et al., 2007). However, the amount and type of heavy metals present in the waste are determined by the manufacturing process (Fowzia and Fakhruddin, 2018). It is thrown into gutters, water drains, open unoccupied plots, and farms indiscriminately by auto technicians and affiliated artisans with workshops on roadsides and open spaces (Anoliefo and Vwioko, 2001). Pollution of water bodies, poisoning of groundwater, and toxicity in animals and plants are all effects. Engine oil is made up of a complicated mixture of hydrocarbons that make up 80 to 90% of its volume and performance-enhancing additives that makeup 10 to 20% of its volume before it is used (Chris, 2007; Mandri and Lin, 2007). Engine oil undergoes a transformation throughout usage due to the breakdown of additives, contamination with combustion products, and the accumulation of metals such as Magnesium, Copper, Zinc, Lead, Cadmium, and others from the engine's wear and tear (Moneke and Nwangwu, 2011; Odukoya et al., 2019). Aliphatic and aromatic hydrocarbons such as phenol, naphthalene, benzo (a) anthracene, benzo (a) pyrene, and fluoranthene are important components of ordinarily used motor oil (Shukry et al., 2013). The illicit dumping of SEO is a worldwide environmental issue with global consequences (Blodgett, 2001). In Buea, Cameroon, Akoachere et al. (2008) identified the discharge of spent crankcase oil from vehicles as a major source of oil pollution. Thenmozhi et al. (2011) and Ugoh and Moneke (2011) both reported soil pollution in the Pudukkottai district of India and the Gwagwalada area of Nigeria, respectively, due to the discharge of old engine oil.

Various pollutants, such as used engine oil and heavy metals, have been discovered to impact soil biochemistry, including microbial characteristics, pH, oxygen availability, and nutrient availability (Ismail et al., 2014). According to recent research, plant roots provide a beneficial environment for bacteria that degrade hydrocarbons (Ismail et al., 2014). Plant age, soil conditions, the genotype of the microorganisms and plants involved, as well as ambient circumstances, all influence the diversity and organization of bacterial communities (Ismail et al., 2014).

Plants are used in phytoremediation to eliminate pollutants from the environment or render them harmless (Ajuziogu et al., 2019). Several plant species have been proven to be capable of growing in polluted soils and extracting pollutants from the growth media. These plants have a variety of functions (Malairajan et al., 2015). Toxic heavy metals can build up in the tissues of some plants (Ndimele et al., 2010). The rhizosphere, or the area around plant roots, has higher populations, diversities, and activity of microorganisms than soil without plants (Ukaegbu-Obi and Omeh, 2014).

Rhizosphere microorganisms are particularly important for plant colonization of unfavorable soils because they can help plants cope with biotic and abiotic stress. As a result, green technology has emerged that uses the symbiotic interaction between plants and their rhizo-microorganisms to break down toxins and clean up the environment. Rhizoremediation is the name for this Microbes in the rhizosphere are sometimes the primary contributors to the degrading process. Exudates from plants are released into the soil ecosystem, increasing microbial activity and assisting in the breakdown of xenobiotics. Enzymes, amino acids, sugars, and low molecular weight carbohydrates are all found in the soluble root exudates (Ukaegbu-Obi and Omeh, 2014). Rhizospheres are also physically stable, eliminating the potentially negative impacts of naturally occurring perturbations on the composition or activity of microbial communities (Ukaegbu-Obi and Omeh, 2014). This stimulating rhizosphere impact has been known for a long time and was initially described by Hiltner in 1904 (Kuiper et al., 2004).

Plant roots provide nutrients other than pollutants to degrading microflora in rhizoremediation, and they also aid in spreading degrading microbes to new areas in the soil (Dunfield and Germida, 2001). Because of their ability to fix nitrogen, legumes have an advantage over other plants in phytoremediation. In oil-contaminated areas, they don't have to fight with microbes and other plants for limited supplies of accessible soil nitrogen. Groundnut (*Arachis hypogea* L.) is a major legume crop that provides an inexpensive source of food for the typical Nigerian. It is a legume that is native to South America, Mexico, and Central America and belongs to the Fabaceae family. It is one of the most important oilseed crops on the planet (Iwo and Obok, 2008; Osuagwu et al., 2017). This study aimed to assess the effect of spent engine oil on some heavy metals and mineral constituents of the rhizosphere of *Arachis hypogaea* L. (Fabaceae).

MATERIALS AND METHODS

The experiment was conducted in the Botanic Garden of the University of Nigeria, Nsukka's Department of Plant Science and Biotechnology, while soil analyses were conducted in the same institution's Department of Soil Science. In a 1:5 ratio, topsoil was mixed with poultry manure (that is 1 kg of poultry manure and 5 kg of topsoil). Before they were employed in the experiment, the mixture was allowed to cool for two weeks. For the planting, ten kilograms of the mixture were placed into several cellophane bags. *A. hypogaea* seeds (3 seeds) were planted at a depth of 5 cm and left to sprout and later trimmed to one plant per bag. The study used a Completely Randomized Design (CRD). This included four (4) treatments (0 - control, 100, 200 and 300 ml of SEO) with nine (9) replicates of each.

After one month of planting, the set-up was polluted with used SEO in different proportions. SEO was employed at concentrations of 0 ml (control), 100 ml, 200 ml, and 300 ml. Soil samples from each treatment were collected two months later and sent to the University of Nigeria, Nsukka's Department of Soil Science for study.

Mineral constituent analyses were performed on soil samples before and after pollution with various quantities of used SEO, using Okonokhua et al. (2007) and Nwite and Alu (2015) techniques.

Table 1. Effect of SEO on the carbon, organic matter and pH of *A. hypogaea* rhizosphere.

Soil treatment	C (%)	OM (%)	pH (H_2O)	pH (KCl)
Control (0 ml)	1.09 ± 0.00^d	2.01 ± 0.00^c	6.90 ± 0.10^b	6.25 ± 0.05^d
100 ml	1.17 ± 0.00^c	2.01 ± 0.00^c	7.60 ± 0.00^a	6.79 ± 0.01^b
200 ml	1.19 ± 0.00^b	2.12 ± 0.00^b	7.75 ± 0.05^a	6.98 ± 0.03^a
300 ml	1.23 ± 0.00^a	2.35 ± 0.00^a	7.60 ± 0.00^a	6.45 ± 0.05^c

Means with different letters as superscripts along a column are significantly different at $p \leq 0.05$.
Source: Authors

pH (H20 and KCl), sodium, potassium, magnesium, calcium, nitrogen, exchangeable acidity, aluminium, and hydrogen were among the minerals tested. The heavy metal content of soil samples was determined using AOAC techniques (2003). In a Kheldjal digestion chamber, a known quantity (10 g) of each of the soil samples was digested with 25 ml conc. H2SO4 and catalyst mixtures until they produced clear liquids. The solution was cooled and diluted with distilled water to a volume of 250 mL before being stored. Chromium, lead, cadmium, iron, and zinc were among the heavy metals examined.

Data analysis

With the help of IBM Statistical Product and Service Solution (SPSS) version 20, the data were subjected to analysis of variance (ANOVA), and significant means were separated using Duncan's New Multiple Range Test (DNMRT).

RESULTS

The percentage carbon concentration significantly ($p < 0.05$) increased with an increase in the concentration of SEO contamination. Soil treated with 300 ml SEO recorded significantly ($p < 0.05$) the highest C. The result also showed a significant increase in organic matter with an increase in SEO concentration. However, 100ml SEO had no significant effect on the organic matter as a control sample and 100 ml SEO recorded similar values (Table 1). There was a significant ($p < 0.05$) increase in the pH of the treated soil compared with that of the control. The pH across the soil treated with different concentrations of SEO did not vary significantly ($p < 0.05$), but were all significantly higher than the pH of the control soil. On the other hand, the result of pH dissolved with KCl varied significantly ($p < 0.05$) within the soil treated with different concentrations of SEO, with soil treated with 200 ml of SEO recording significantly the highest pH value (Table 1).

The effect of SEO on soil exchangeable cations was also evaluated and presented in Table 2. Percentage nitrogen significantly ($p < 0.05$) increased in 200- and 300- ml SEO treated soil samples as compared to the control, while soil treated with 100ml concentration did not differ from the control. The percentage base salt showed a significant ($p < 0.05$) dose-dependent decrease across the treated soil. Na^+ was also observed to increase with pollution, with soil treated with 300 ml SEO having significantly the highest concentration while the control soil had the lowest. The control soil had the lowest Ca^{2+} when compared with the treated soils and there was a significant increase in the Ca^{2+} with an increased concentration of SEO treated samples. There were no significant differences for K^+ and Mg^{2+} across the control and treatment groups. The H^+ increased during the experiment from 1.27 ± 0.01 me/100 g in the control soil to 1.67 ± 0.00 me/100 g in the 300 ml SEO treated soil. Available phosphorus was similarly found to increase significantly ($p < 0.05$) with the application of SEO in a dose-dependent manner (Table 2).

The result as presented in Figure 1 shows the particles size parameters of the soil rhizosphere of *A. hypogaea.* The percentage of clay and fine sand in the soil samples polluted with 100 and 200ml SEO decreased significantly ($p < 0.05$) when compared with the control. The concentration of silt was higher in treated soils compared with the control. However, the increase in the silt content was not significant except between the control and 100 ml treatment (Figure 1).

The result presented in Table 3 shows the heavy metal concentration of *A. hypogaea* rhizosphere treated with different concentrations of SEO compared with the control soil. The lead concentration ranged from 0.59 to 1.92 mg/kg across the treatments. There was a dose-dependent increase in lead concentration with the control soil recording significantly the lowest (0.57 ± 0.00 mg/kg) compared with the samples treated with SEO. Chromium and Cadmium all had a concentration below 0.001 mg/kg across the different treatments during the experiment. Similarly, there was an improvement in the iron and zinc concentration with increased concentration of SEO treatment. The iron concentration ranged from 1.65 to 1.73 mg/kg with soil treated with 300 ml SEO recording significantly ($p < 0.05$) with the highest concentration and the control soil with the least value. The zinc concentration was increased significantly ($p < 0.05$) with the application of SEO in a dose-dependent manner.

DISCUSSION

The goal of this study was to see how discarded engine

Table 2. Effect of SEO on %N, available P and exchangeable cations of *A. hypogaea* rhizosphere.

	%				(me/100 g)					
Soil treatment	**N**	**Base salt**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**CEC**	**Al^{3+}**	**H^+**	**AP (ppm)**
Control (0 ml)	0.06 ± 0.00^b	67.46 ± 0.01^a	0.06 ± 0.00^c	0.12 ± 0.00^a	2.94 ± 0.00^d	1.26 ± 0.01^a	8.54^c	-	1.27 ± 0.01^d	59.57^b
100 ml	0.06 ± 0.00^b	66.27 ± 0.00^b	0.07 ± 0.00^b	0.12 ± 0.00^a	2.87 ± 0.00^c	1.26 ± 0.00^a	9.23^b	-	1.44 ± 0.00^c	58.43^b
200 ml	0.07 ± 0.00^a	61.07 ± 0.04^c	0.07 ± 0.00^b	0.12 ± 0.00^a	3.01 ± 0.00^b	1.25 ± 0.00^a	9.34^b	-	1.57 ± 0.01^b	60.26^a
300 ml	0.07 ± 0.00^a	54.94 ± 0.00^d	0.08 ± 0.00^a	0.11 ± 0.00^a	3.33 ± 0.00^a	1.25 ± 0.00^a	9.61^a	-	1.67 ± 0.00^a	61.33^a

*Means with different letters as superscripts along a column are significantly different at $p \leq 0.05$.
Source: Authors

Table 3. Effect of SEO on the heavy metals of the *A. hypogaea* rhizosphere.

Soil treatment	**Lead (mg/kg)**	**Chromium (mg/kg)**	**Cadmium (mg/kg)**	**Iron (mg/kg)**	**Zinc (mg/kg)**
Control (0 ml)	0.57 ± 0.00^d	< 0.001	< 0.001	1.66 ± 0.00^d	0.95 ± 0.00^d
100 ml	0.59 ± 0.00^c	< 0.001	< 0.001	1.69 ± 0.00^c	1.34 ± 0.00^c
200 ml	0.62 ± 0.00^b	< 0.001	< 0.001	1.70 ± 0.00^b	1.36 ± 0.00^b
300 ml	1.89 ± 0.00^a	< 0.001	< 0.001	1.73 ± 0.00^a	1.48 ± 0.00^a

*Means with different letters as superscripts along a column are significantly different at $p \leq 0.0$.
Source: Authors

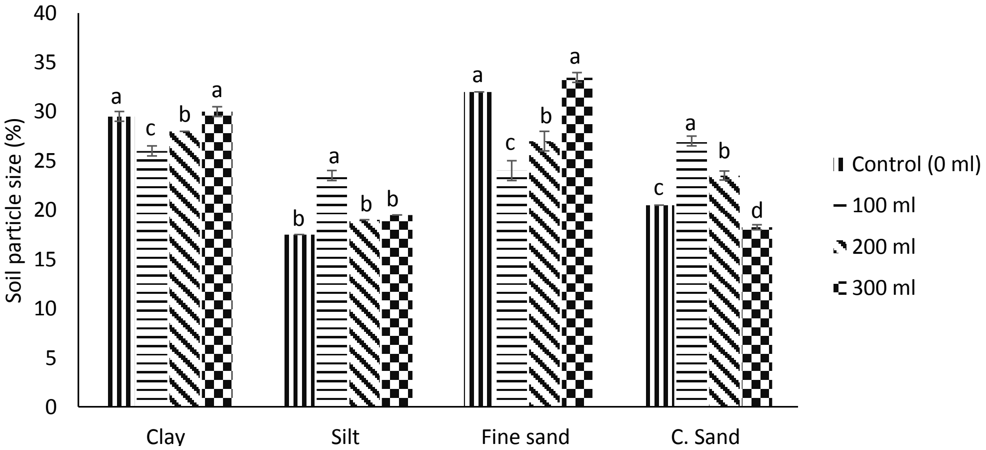

Figure 1. Effect of SEO on the particle size of *A. hypogaea* rhizosphere.
Source: Authors

oil affected the rhizosphere of *A. hypogaea*. SEO raised the percentage of organic carbon and organic matter in the rhizosphere of *A. hypogaea* considerably. This large increase in C and OM in the treated soil compared to the control could be ascribed to soil contamination by the spent engine oil.

This was in line with previous results from researchers who conducted similar investigations and discovered that applying used engine oil to the soil could enhance organic carbon levels (Okonokhua et al., 2007; Nwite and Alu, 2015).

This could be due to contamination caused by the mineral elements present in the oil. In comparison to control, Okonokhua et al. (2007) found an increase in carbon and nitrogen in used lube oil-treated soil. At low pH, metal retention to soil organic matter is less, resulting in more readily available metal in the soil solution for root absorption.

This could also explain why the organic matter in the control soil was lower than in the treated soils (Nwite and Alu, 2015). SEO pollution caused a considerable increase in pH, according to the findings. This contradicts prior claims that SEO pollution lowers soil pH (Okonokhua et al., 2007; Nwite and Alu, 2015). There was no significant variation in pH between control and wasted oil-treated soil, according to Osuji and Nwoye (2007), Okonokhua et al. (2009), and Nwite and Alu (2015). The increase in pH, on the other hand, could indicate that *A. hypogaea* is a good phytoremediator. The variation could be due to interactions between the organisms found in the test plant's rhizosphere and SEO. The root nodules' association with nitrogen-fixing bacteria may have increased remediation efficiency (Ogbo et al., 2009), as evidenced by the high pH values, which were almost neutral to alkaline. According to Desai and Vyas (2008), greater soil pH ranging from 7 to 8 has been found to facilitate optimal microbial breakdown in the environment (Desai and Vyas, 2006). The study found differences in particle size; however, the texture of the sand did not differ between the treatments, according to USDA (2017) classification. All of the samples fell within the sandy clay loamy soil texture category.

According to Agbogidi and Enujeke (2012), SEO did not influence the physical qualities of the soil, but visual examination revealed that plots that got wasted oil (SEO) treatment had less water infiltration and percolation in the soil. When compared to the control, a significant (P 0.05) increase in soil nitrogen and accessible phosphorus was seen at 200 ml and 300 ml concentrations. In contrast, Kayode et al. (2009) found lower nitrogen levels in soil treated with waste lube oil (SEO). The nutrient composition may have been improved as a result of the rhizosphere effect. It could be due to the legume's ability to fix nitrogen. However, some studies have found that applying spent engine oil to soil has a positive effect since it can improve the organic carbon and nitrogen content of the soil (McLaren et al., 2005; Odukoya et al., 2019). This is because, at low pH, many metal cations are more soluble and accessible in the soil solution (Odukoya et al., 2019). The relative quantity and availability of various important nutritional components are indicated by the exchangeable base distribution. For Ca and Mg, a cation concentration of around 2 mg/100g soil is regarded appropriate, whereas, for K, 0.2 mg/100g soil and above is considered adequate. The results revealed that higher SEO concentrations resulted in a considerable rise in CEC. Ca levels were also observed to be greater in SEO-polluted soil.

In comparison to the control, there was an increase in Fe and Zn concentrations in polluted soil. This is in line with the findings of McLaren et al. (2005) and Odukoya et al. 2019), who found that petroleum oil contamination improves soil content with some nutrient elements such as Mg, K, P, Na, Fe, and Zn, and has a substantial impact on plant chemical composition. The potassium and magnesium contents of the polluted soils were found to be lower than the needed values for the cultivation of specific crops, even though there was no significant difference between the contaminated and control samples (Kayode et al., 2009). In the contaminated rhizosphere of the plant, SEO raised the concentration of lead in a dose-dependent manner. The build-up of lead in SEO could be to blame for the increase in Pb content in the treated soil.

This is consistent with the findings of Delorme et al. (2001), who found that SEO becomes contaminated with heavy metals as a result of engine wear and strain. Heavy metals uptake by crops was observed by Adweole et al. (2008), who also noted that these heavy metals were stored in crop parts. The assumption is that heavy metal poisoning poses a threat to humans. According to the findings of Anikwe and Nwobodo (2002) and Asadu et al. (2008), humans are in danger of heavy metal toxicity if they consume foods cultivated in areas polluted with heavy metals due to heavy metals eco-toxicity. This might be conceivable if heavy metals are recycled via the food chain. Lead and cadmium are heavy metals that can harm a person's brain, kidneys, or reproductive system. The uptake of lead by maize grains was often greater than that of cadmium. This shows that eating crops produced on used engine oil-treated soils exposes man to an increased risk of lead poisoning.

Conclusion

As seen in this study, SEO applications generated certain alterations in soil chemistry. SEO application did not negatively alter soil texture, but it did greatly improve soil cation exchange capacity, nitrogen, accessible phosphorus, and other mineral nutrients, according to the study. Despite heavy metal deposition, the groundnut plant's rhizosphere action may have improved the mineral contents of the soil. However, more research is needed to determine the metal uptake by the plant and its potential use in phytoremediation.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

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