Chapter

Mercury Contamination and Spill-over at Human-Wildlife-Environment Interface

Andrew Tamale, Justine Okello and Celsus Sente

Abstract

Man's quest for energy demands that fuel for running machines and cooking is vital for mankind. Oil and coal have served this energy quest for time immemorial. This oil quest has been present in the Albertine Graben since 1920, threatening biodiversity spots, terrestrial wildlife, and aquatic resources. The current book chapter provides insights into the spatial distribution of potentially toxic elements (Mercury) in terrestrial and marine species and the health risk posed to terrestrial and aquatic species due to oil exploitation.

Keywords: oil spill, mercury, Lake Albert Graben, human-wildlife environment interface, developing country

1. Introduction

Pollution is a resultant detrimental effect on the ecosystem attributed to hazard discharges and mismanagement [1, 2]. Contamination on the other hand is attributed to presence of hazards in the biological systems and these act as sources of toxicity to flora and fauna [3]. Potential toxic elements (PTEs), another type of inorganic pollutant, make up one of the most significant groups of pollutants that are released into environment by chemical and allied industries such as pharmaceuticals, fertilizers, and refineries. These PTEs can pollute the environment if their concentration is higher than the allowable limits [4]. There is a possibility that these inorganic pollutants cannot be broken down by biological processes, and as a result, they remain in the environment for a while, ultimately causing disruptive effects, not only on public health but also on the flora and fauna of aquatic and terrestrial environment [5, 6]. Potentially toxic elements are a threat on a global scale since they are not biodegradable and have a propensity to build up in living organisms through the food chain. Different body organs in both humans and animals are impacted by a number of potentially toxic substances' causing acute and chronic toxic effects [1, 6]. In many Sub-Saharan African countries, anthropogenic activities that occur within an ecosystem, as well as the natural sources, are the two main contributors to PTEs pollution.

The vast majority of pollution is caused by human activities, such as the search for new sources of energy [7, 8]. Since the beginning of time, coal and oil have been sources of energy for a wide variety of applications across the globe.

In Uganda, oil exploration in the Lake Albert Graben that began as early as 1938 in Butiaba, Buliisa with geological explorations, has today evolved into the construction of an oil pipeline [9]. Such pipelines come along with the threat of pipeline accidents where oil spills are eminent [10]. The Uganda environmental policy stipulates that oil spills are one of the disasters whose level of contamination of the environment would warrant attention [9]. According to Kassim [2], oil resources should be managed in cognition of the negative effects such as pollution and contamination. The environmental policy stipulates that oil spills are one of the disasters whose level of contamination of the environment would warrant attention [11]. The pollution cited in this situation is that of potentially toxic elements, especially mercury and lead. Since "oil spill" is often a new phenomenon in the area, the ecosystems should be able to adapt in a compatible way otherwise the ecosystem collapses. The theory of sustainable utilization for oil resources in the Lake Albert Graben focuses on three main areas namely; availability of the resources, adaptability and flexibility, and homeostasis [12]. The resources targeted at the Albertine Graben include water, assets, and entitlements, and not so much of PTEs research [13]. For instance, much of the work executed about water levels of mercury, levels of mercury in fish, and risk burden thereafter, is documented better in developed countries compared to the developing countries, like Uganda. The use of consumption advisories is where most of the information in developed countries is stored. The assets in the biodiversity hot spot include flora and fauna uniquely found in this site [14]. In addition to the animal species and plants in the protected area, lies a whole new industrial park as part of the oil city. The much-anticipated livelihood from this oil city creates an entitlement to the community around the oil drilling area [14]. However, conflicts might result in negative catastrophes, such as oil leaks, if the delicate balance between entitlement and livelihood is not realized. In the Murchison Falls Conservation Area (MFCA), wildlife, domestic animals, and human ecosystems are documented as resilient systems, initiated by anthropogenic activities [15]. The presence of oil and gas prospecting in MFCA as major anthropogenic activities translates into ecosystem resilience, coping, and tolerance as a result of the possible oil spills [15]. Oil and gas production is one of the precursors of mercury in the environment, should there be an oil spill [16]. The surrounding communities are being empowered through a socioecological approach that focuses on sustainability of the ecosystem proponents.

This chapter, therefore, discusses the detrimental effects of mercury on an ecosystem that lies at the wildlife, domestic animal, and human interface. These effects are on around an oil spill framework that encompasses terrestrial and aquatic environments, species, and habitats as illustrated in **Figure 1**.

The likely exposure factors include exposure time, exposure quantity, and analytic chemicals, that is, mercury and lead. The species-related factors include species identity, development stage, generation time, feeding mode, and mobility. The habitat related factors include depth at which species thrive, environmental stressors, i.e., deforestations, erosion, anthropogenic activities and climatic conditions. These triad factors also are both inter and intra linked.

Location and habitat.

In the Lake Albert region, oil exploration often excites the population. However, the location of oil wells in MFCA biodiversity hot spots and forests has led to loss of habitat and ecosystem for biodiversity. The location of MCFA has been illustrated in **Figures 2** and **3**.

Figure 1.
Framework of oil spill burden on Ecosystem. Sources: [17, 18].

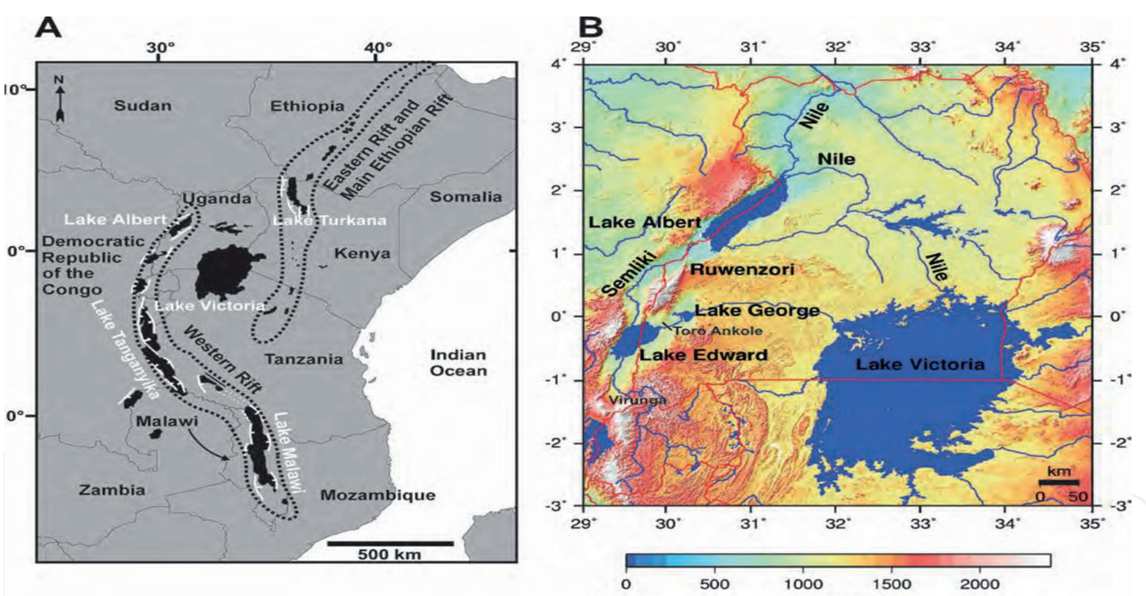

Figure 2.
Map of Lake Albert region [19].

Regardless of where the oil spill occurs, whether terrestrial or aquatic, the impacts are devastating, as they can lead to accumulation of potentially toxic elements, especially mercury in the terrestrial and aquatic environment, causing toxicities in animals and humans. Mercury in particular bioaccumulates and is magnified along trophic levels, often bioconcentrate in plants and animals and the flora acts as sources of the potentially toxic substances/mercury.

On the other hand, there have been positive impacts on development, that is, infrastructure, road networks, and improved livelihoods of the surrounding communities. A balance is needed in utilization of the oil resource since it is perishable but can also have vast negative impacts, which include the oil spills.

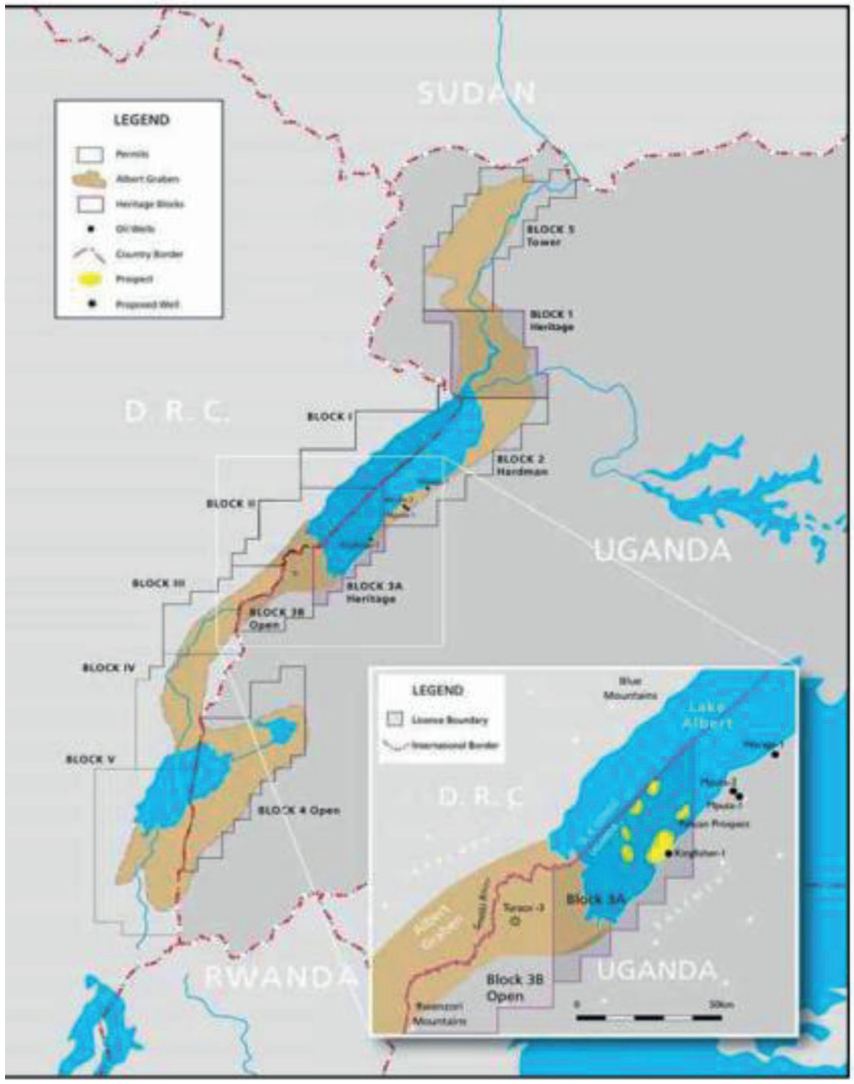

Figure 3.
Oil fields in Uganda [20].

2. Species

The conservation world is aware of the burden of oil spills in the areas where oil exploration and extraction exist. These oil spills mainly negatively affect the wildlife (flora and fauna), fishing communities, and the communities in and around the wildlife-protected areas. To safeguard these vulnerable populations at the animal-environment-human interface, solutions on how to mitigate the levels of potential toxic substances found in water, plants, and animals need to be found. This information is displayed as a distribution map of the key levels of lead and mercury in food eaten by communities in the protected areas, and associated health risks. The adverse effects of lead and mercury on wildlife, aquatic species, and environment also need to be documented. These documents translate into the food consumption advisories for lead and mercury in the MFCA. The awareness of risks and benefits associated with eating fish, plants, and wildlife from MFCA is vital for tourists and communities around the protected area. Since most of the mercury is taken in through fish consumption, vulnerable populations should watch out for the fish species eaten, especially the carnivorous fish. The vulnerable populations include children less than 12 years, women of childbearing age, and elderly.

3. Anthropogenic activities

Anthropogenic activities offer a delicate balance between the needs of a community/government and the biodiversity spots and their contribution to nature [21]. The country's development process should be in tandem with the environmental concerns [20]. Therefore, activities like oil exploration in biodiversity spots should be allowed to execute with guiding regulations and policy. If the works go on unregulated, the destruction to the environment and the associated costs of restoration are quite prohibitive. The cost of an oil spill to wildlife range from losses due to acute toxicity of the aquatic and terrestrial species, the cost of rehabilitation of those that can be recovered, and the cost of clean up to and the length of 1300 km length of the oil pipe for crude oil. The work on oil spills is much needed in the Lake Albert Graben given the fact that 4 million gallons per day in the kingfisher project shall be produced come 2023. The Lake Albert Graben has over 7 blocks of which the kingfisher project lies in one of the blocks [2, 22]. The Lake Albert Graben is synonymous with the Niger delta in Nigeria. Oil-related studies in Nigeria exhibited a range of between 230 and 1200 spills per year in the Niger delta between 1981 and 2015 [3]. The amounts per oil spill in the oil mining areas and between the path of oil pipelines can only be estimated to be between 50,000 barrels and 300,000 barrels per year in the same study period in Niger delta [3]. Based on the oil spills, fish are contaminated with potentially toxic substances and this not only leads to health risks in high-level trophic fish but also has a negative effect on fish breeding in the water sources. Adding the restoration costs to the 3.5 billion US$ initial cost of construction of the pipeline is a tall order [3].

3.1 Hazards

Pollution attributed to quest for energy in Uganda and world over is related to cancers and other severe health burdens to animals and humans. Some of the detrimental hazards associated with oil spills are potentially toxic substances, especially mercury. Considering the Lake Albert Graben where oil wells are located both inland and in lake water, aquatic fish and captive animals will be exposed to levels of Mercury exceeding the maximum allowable limits of WHO and FAO. Exposure of animals and aquatic species to Mercury results in neurotoxicity, kidney damage, cancers, and teratogenicity [6, 10, 23]. One of the gaps identified in the study is the absence of an investigation into the establishment of potentially toxic substances levels in plants, wildlife, and aquatic species, establishment of the associated health risks, and lack of the PTEs distribution map for the MFCA.

The hazard identification study employs teams of epidemiologists, researchers, wildlife veterinarians, game park staff, statisticians, lab specialists, and policy analysts. The study approach utilizes quantitative approach of research involving semi-structured interviews, sample collection, lab investigation, data mining, and dissemination of findings/report/policy and these translate into risk assessments. The evidence generated is what is utilized to reduce oil pollution effects on wildlife and aquatic species in MFCA. Efforts like these steer the reduction of pollutants in areas where biodiversity is paramount and sustainable management of the ecosystem is warranted. Areas that have oil wells and parks in Uganda and other developing countries can utilize study findings to design appropriate interventions for reduction in the negative effects of oil spills in the MFCA. The resultant interventions will result in ecosystem recovery.

3.2 Current literature

Pollution attributed to expedition for energy in Uganda and world over is closely linked to several health burdens to animals, humans, and environment [24]. This evidence can be much more pronounced in the potentially toxic substances, which have been documented to cause cancers in animals and human populations [19, 23, 25]. Furthermore, the plants have equally been shown to contain traces of potentially toxic elements in amounts beyond acceptable levels [23]. It is imperative to note that some of the detrimental hazards associated with extraction and refining of petroleum and associated products are the oil and potentially toxic elements spill-overs [3, 26]. Mercury and its compounds are one such PTEs that is linked to deleterious effects in the nervous system, kidneys, and liver and disturb immune response processes, causing tremors, impaired vision and hearing, paralysis, and emotional instability [27, 28]. Mercury is one of the most common contaminants associated with oil spills [29]. Methods of biological control where eco-friendly bacteria can be utilized to solve the issue of environmental degradation post an oil spill have been attempted [30].

3.3 Mercury entry into the ecosystem

At the human-animal-environment interface, mercury can exist in three forms; elemental (or metallic) mercury, inorganic mercury compounds, and organic mercury compounds. At this point, mercury can be highly persistent, bioaccumulative, and toxic. Mercury occurs naturally in the environment, but it is generally safely contained in minerals and does not present any significant risk, except when anthropogenic activities precipitate its release in large amounts into the environment, consequently circulating freely for a long time [31]. An environment can grossly become polluted with mercury following oil and gas leaks, alkali and metal processing, coal incineration, gold and mercury mining, and from improper medical and other waste disposals. In the environment, microbial organisms can uptake the elemental form of mercury and this signals the transcription of the genes hgcA and hgcB are transcribed to synthesize the HgcA and HgcB proteins [32].

These proteins can then start the methylation reaction to form methylmercury. Mercury and methylmercury exposure to sunlight (specifically ultra-violet light) has an overall detoxifying effect. Sunlight can break down methylmercury to Hg(II) or Hg(0), which can leave the aquatic environment and reenter the atmosphere as a gas as shown in **Figure 4**.

In the food chain, each rung of the food chain consumes more mercury because animals acquire it faster than they expel it. Small ambient quantities of methylmercury can easily build in fish, fish-eating species, and people. Even at low atmospheric deposition rates in remote regions, mercury biomagnification can be harmful to aquatic food chain consumers.

Mercury-associated risks at the wildlife-domestic animal-environment interface.

mercury in water and sediments is the primary concern, as it is in a highly toxic form and can easily be taken up by animals, thus finding its way into the human food chain. Health concerns in Uganda center on human and animal consumption of fish and fish products contaminated with methylmercury. Particularly in humans, neurotoxicity is the most important concern associated with mercury exposure. When methylmercury reaches the bloodstream, it is distributed to all tissues and can cross the normally protective blood–brain barrier to the brain. Methylmercury can also readily move through the placenta to the developing fetus(es) and, therefore, of

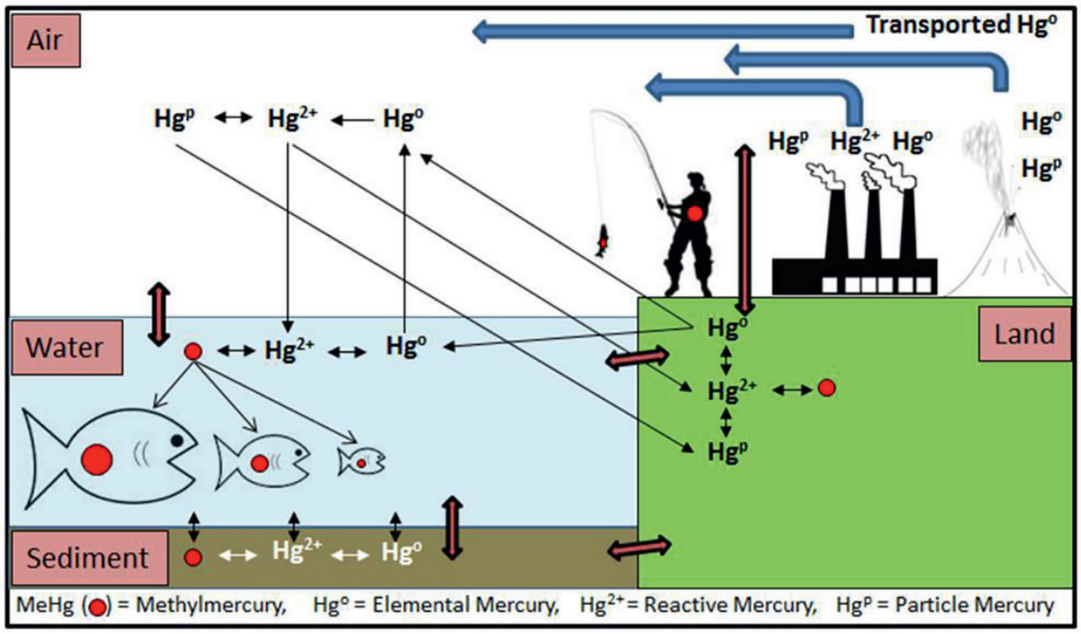

Figure 4.
Mercury's entry into the environment [33].

more concern to pregnant women and women of childbearing age. Mercury exposure in humans (RfD between 1.0 and 3.0×10^{-4} mg/kg per day) can lead to a variety of negative health effects, including neurological, kidney, gastrointestinal, genetic, cardiovascular, and developmental disorders, and even death [32]. Wildlife and domestic animals that consume fish and fish products, depending on their feeding behavior, may ingest large amounts of methylmercury in their diet, often interfering with their reproductive potential. Raptorial bird species, otters, and others that commonly consume water-based foods are at the greater risk of mercury contamination. In birds, reproductive problems are the primary concern related to mercury poisoning. Other mercury effects in wildlife and other animals are liver damage, kidney damage, and neurobehavioral effects.

4. Health risk and burden due to mercury

The exposure diet intake is linked to the Hazard Quotient (HQ), which signifies the relationship between the exposure obtained in the diet and the oral reference dose for mercury [28]. Choice of the oral reference dose is critical in determining the health risks the vulnerable community is exposed to, that is, use of the general population or vulnerable population oral reference dose [34]. The oral reference doses for mercury in the vulnerable and general population are 1×10^{-4} and 3×10^{-4} mg/kg per day, respectively [35, 36]. Therefore, there is a need to send out a message to this vulnerable group about the health hazard they are encountering daily by consumption of food contaminated with mercury. Use of specific messages for different target groups was demonstrated in the USA during a study by Ref. [34], which involved pregnant women and children and observed that there is a need for a unique message for the vulnerable group.

Hazard Index (HI) for both vulnerable and general populations if computed can spell out the health risk. For the vulnerable populations, if the hazard quotients from the study are added and the hazard index is greater than one spells out probable health risks from the mercury consumed. These results are in agreement with Poulin et al. [29] who documented higher HI levels in carnivorous than herbivorous fish, a pointer toward the hazard index points toward noncarcinogenic risk attributed to mercury uptake in fish parts, especially the Lake Albert Nile perch.

5. Conclusions

Mercury and other potentially toxic substances associated with oil spills are a common occurrence in areas of oil exploitation. The negative effects of oil spills can be reduced by environmentally friendly human approaches and the resilience of the ecosystem. Oil exploitation is an investment that should be executed carefully in accordance with guidelines and policy. This oil investment can transform community and country livelihoods positively if managed in accordance with the eco-friendly guidelines and negatively if the sole focus of oil extraction is that of resource generation for country expenditures.

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Conflict of interest

There is no known conflict of interest to declare on behalf of the authors.

Notes/thanks/other declarations

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References

[1] Chowdhary P, Bharagava RN, Mishra S, Khan N. Role of industries in water scarcity and its adverse effects on environment and human health. In: Environmental Concerns and Sustainable Development. Singapore: Springer; 2020. pp. 235-256 [Accessed: 02 Sep 2022]

[2] Kassim W. 2020. Land conservation in the albertine graben region of uganda: A critical analysis of the legal regimes. In: Springer. pp. 79-99. [Online] Available from: https://link.springer.com/chapter/10.1007/978-3-030-36004-7_5. DOI: 10.1007/978-3-030-36004-7_5 [Accessed: May 19, 2022]

[3] Osuagwu ES, Olaifa E. Effects of oil spills on fish production in the Niger Delta. PLoS One. 2018;**13**(10):e0205114. DOI: 10.1371/JOURNAL.PONE.0205114

[4] Brudler S, Rygaard M, Arnbjerg-Nielsen K, Hauschild MZ, Ammitsøe C, Vezzaro L. Pollution levels of stormwater discharges and resulting environmental impacts. Science of the Total Environment. 2019;**663**:754-763

[5] Cao Y, Li X. Adsorption of graphene for the removal of inorganic pollutants in water purification: A review. Adsorption. 2014;**20**(5):713-727

[6] Balali-Mood M, Naseri K, Tahergorabi Z, Khazdair MR, Sadeghi M. Toxic mechanisms of five heavy metals: Mercury, lead, chromium, cadmium, and arsenic. Frontiers in Pharmacology. 2021;**12**:227. DOI: 10.3389/FPHAR.2021.643972/XML/NLM

[7] Men C, Liu R, Wang Q, Guo L, Shen Z. The impact of seasonal varied human activity on characteristics and sources of heavy metals in metropolitan road dusts. Science of the total Environment. 2018;**637**:844-854

[8] Gao Y et al. Human activities aggravate nitrogen-deposition pollution to inland water over China. National Science Review. 2020;**7**(2):430-440

[9] Sseremba D. Oil and community development in uganda citizens' expectations and participation in the oil and natural gas sector. 2020. [Online] Available from: https://www.theseus.fi/handle/10024/332985. [Accessed: May 19, 2022]

[10] America's Dangerous Pipelines. Available from: https://www.biologicaldiversity.org/campaigns/americas_dangerous_pipelines/. [Accessed Sep. 02, 2022]

[11] Sabela-Rikhotso PTZ, van Niekerk D, Nemakonde LD. Enhancing Coordination for Effective Management of Oil Spill Pollution in South Africa. International Journal of Disaster Risk Science. 2022;**13**:12-24. Available from: www.ijdrs.com. www.springer.com/13753. DOI: 10.1007/s13753-022-00392-8

[12] Molyneaux L, Brown C, Wagner L, Foster J. Measuring resilience in energy systems: Insights from a range of disciplines. Renewable and Sustainable Energy Reviews. 2016;**59**:1068-1079. DOI: 10.1016/J.RSER.2016.01.063

[13] Kabenge I, Katimbo A, Kiggundu N, Banadda N. Bioremediation technology potential for management of soil and water pollution from anticipated rapid industrialization and planned oil and gas sector in Uganda: A review. Journal of Environmental Protection. 2017;**8**(11):1393-1423

[14] Mawejje J. The oil discovery in Uganda's Albertine region: Local expectations, involvement, and impacts.

The Extractive Industries and Society. 2019;**6**(1):129-135

[15] Nnakayima D. Impacts of upstream oil and gas activities on environment, well-being and tourism in the Albertine Region of Uganda: Local community perspectives. Unpublished masters dissertation. Kampala, Uganda: Makerere University. 2018

[16] Qiao K et al. Application of magnetic adsorbents based on iron oxide nanoparticles for oil spill remediation: A review. Journal of the Taiwan Institute of Chemical Engineers. 2019;**97**:227-236

[17] The-ocean-off-the-coast-of-Lima-shines-with-oil-spilled-from-the-refinery-of-La-Pampilla-Peru.webp (WEBP Image, 1536 × 800 pixels) — Scaled (76%). Available from: https://imgs.mongabay.com/wp-content/uploads/sites/20/2022/03/25140533/The-ocean-off-the-coast-of-Lima-shines-with-oil-spilled-from-the-refinery-of-La-Pampilla-Peru.jpg. [Accessed Aug. 30, 2022]

[18] Shell oil spills in the Niger delta - in pictures - Environment - The Guardian. Available from: https://www.theguardian.com/environment/gallery/2011/aug/03/shell-oil-spills-niger-delta-in-pictures. [Accessed Aug. 30, 2022]

[19] Andrew T, Francis E, Charles M, Naigaga I, Jessica N, Micheal O, et al. Mercury concentration in muscle, bellyfat and liver from Oreochromis niloticus and Lates niloticus consumed in Lake Albert fishing communities in Uganda. Cogent Food Agriculture. 31 Dec 2016;**2**(1):1214996. DOI: 10.1080/23311932.2016.1214996. Epub: 2016 Jul 22. PMID: 27774497; PMCID: PMC5059776

[20] Steinhauer I, van Bodegom A, van Dessel B. Review of the Environmental and Social Impact Assessment (ESIA) Report for the Kingfisher Project in Uganda oil spill. 2019. [Online]. Available: https://dspace.library.uu.nl/bitstream/handle/1874/396567/NCEA_7308_NCEA_Review_of_ESIA_Report_for_Kingfisher_Project_Uganda.pdf?sequence=1. [Accessed: Sep. 02, 2022]

[21] Pullin AS et al. Human well-being impacts of terrestrial protected areas. Environmental Evidence. 2013;**2**(1):1-41. DOI: 10.1186/2047-2382-2-19/TABLES/5

[22] Sylvia K. Analysing the effects of oil and gas exploration activities on people's livelihoods in the Albertine graben in western Uganda. 2021. [Online]. Available from: https://kyuspace.kyu.ac.ug/handle/20.500.12504/393. [Accessed: May 19, 2022]

[23] Mitra S, et al. Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. Journal of King Saud University - Science. 2022;**34**(3). DOI: 10.1016/j.jksus.2022.101865

[24] Fuda RK, Ryan SJ, Cohen JB, Hartter J, Frair JL. Assessing impacts to primary productivity at the park edge in Murchison Falls Conservation Area, Uganda. Ecosphere 7.RemoteXs. Wiley Online Libr; 2018;(10):e01486. DOI: 10.1002/ecs2.1486. [Online]. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/aje.12568 [Accessed: May 19, 2022]

[25] Liang L, Xi F, Tan W, Meng X, Hu B, Wang X. Review of organic and inorganic pollutants removal by biochar and biochar-based composites. Biochar. 2021;**33**:255-281. DOI: 10.1007/S42773-021-00101-6

[26] Karunasagar I, Girisha SK, Venugopal MN, Biswajit M. Bacteriophage application as a management strategy in shrimp hatcheries. Communications in Agricultural and Applied Biological

Sciences. 2013;**78**(4):204-205 [Online]. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25141668

[27] Tamale A, Ejobi F, Muyanja C, Naigaga I, Nakavuma J, Drago CK, et al. Sociocultural factors associated with fish consumption in Lake Albert fishing community: Guidelines for lead and mercury. Cogent Environmental Science. 21 Mar 2017;**3**(1):1304604. DOI: 10.1080/23311843.2017.1304604. PMID: 30854410; PMCID: PMC6390268

[28] Castilhos ZC et al. Mercury contamination in fish from gold mining areas in Indonesia and human health risk assessment. Science of the Total Environment. 2006;**368**(1):320-325. DOI: 10.1016/J.SCITOTENV.2006.01.039

[29] Poulin J, Gibb H, Prüss-Üstün A, World Health Organization. Mercury: assessing the environmental burden of disease at national and local levels. Geneva: World Health Organization; 2008. Available from: https://apps.who.int/iris/ handle/10665/43875. [Accessed: Sep. 02, 2022]

[30] Ssenku JE, Walusansa A, Oryem-Origa H, et al. Bacterial community and chemical profiles of oil-polluted sites in selected cities of Uganda: Potential for developing a bacterial-based product for remediation of oil-polluted sites. BMC Microorganisms. 2022;**22**:120. DOI: 10.1186/s12866-022-02541-x

[31] Rice KM, Walker EM, Wu M, Gillette C, Blough ER. Environmental mercury and its toxic effects. Journal of Preventive Medicine and Public Health. 2014;**47**(2):74-83. DOI: 10.3961/JPMPH.2014.47.2.74

[32] Tang WL, Liu YR, Guan WY, Zhong H, Qu XM, Zhang T. Understanding mercury methylation in the changing environment: Recent advances in assessing microbial methylators and mercury bioavailability. Science of the Total Environment. 20 Apr 2020;**714**:136827. DOI: 10.1016/j.scitotenv.2020.136827. Epub: 2020 Jan 22. PMID: 32018974

[33] Floreani F, Acquavita A, Barago N, Klun K, Faganeli J, Covelli S. Gaseous mercury exchange from water-air interface in differently impacted freshwater environments. International Journal of Environmental Research and Public Health. 2022;**19**(13):8149. DOI: 10.3390/ijerph19138149

[34] What to tell your clients about eating fish. Available from: https://agris.fao.org/agris-search/search.do?recordID=US201300990192. [Accessed Sep. 03, 2022]

[35] Zhu L, Yan B, Wang L, Pan X. Mercury concentration in the muscle of seven fish species from Chagan Lake, Northeast China. Environmental Monitoring and Assessment. 2012;**184**(3):1299-1310. DOI: 10.1007/S10661-011-2041-7

[36] Andrew T, Francis E, Charles M, Irene N, Jesca N, Ocaido M, et al. Risk estimates for children and pregnant women exposed to mercury-contaminated Oreochromis niloticus and Lates niloticus in Lake Albert Uganda. Cogent Food Agriculture. 31 Dec 2016;**2**(1):1228732. DOI: 10.1080/23311932.2016.1228732. Epub: 2016 Sep 8. PMID: 27722183; PMCID: PMC5039401