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ORIGINAL RESEARCH ARTICLE

Occupational exposure risk to radiation in open cast artisanal and small-scale gold mining in Western Kenya

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ABSTRACT
Artisanal and small-scale gold mining (ASSGM) is practiced at open-cast gold mines in Western Kenya. Mining is still going on in deep mines, with huge tailings littering the workplace for most miners. This mining exercise brings to the surface myriad radioactive materials from the earth's crust, which pose physical and radiation hazards to miners. The aim of this study was to determine occupational exposure to radiation at artisanal gold mining sites. Four sites were studied for a period of six months. Environmental radiation exposure levels were measured using the Geiger Mueller tube (GMT) model; PHYWE, whereas thermoluminescent dosimeter badges (TLB) 802A were used to record personal radiation exposure levels. d-Orbital Limited Company provided UD-716AGL, used to read the radiation levels from the TLB. Exposure levels were reported in terms of monthly skin, eye, and body exposures. Results revealed an increase in counts per minute with an increase in depth in a range of 19.83 ± 3.87 to 27.83 ± 2.10 and a mean of 23.62 ± 5.17 cpm. Personal effective radiation exposure doses for the skin, eye and body were 0.19 ± 0.01, 0.19 ± 0.01 and 0.18 ± 0.015 for two sites in Western Kenya, whereas those in Nyanza had 0.27 ± 0.01, 0.27 ± 0.01 and 0.25 ± 0.05 mSv on skin, eye and body. The maximum dose threshold limit was estimated at 1.67 mSv per month. There was no significant difference in the radiation exposure of the eye, skin, and body between the sites as indicated by $\chi 2 = 2.0$ and $p = 0.157$ (at $p<0.05$) with $df = 1$. The study revealed that workers are exposed to ionising radiation, but the measured levels were within safe limits.

Key words; Artisanal, gold, mining, exposure, occupational, radiation, health

1.0 Introduction
Artisanal gold mining contributes significantly to the growth and development of Kenya's economic system. Artisanal gold mining has been taking place in Kenya's western and northern regions for more than 50 years. Despite the fact that it is a significant source of money for both the local and national economies, artisanal gold mining is also responsible for a number of environmental harms, including tailing waste disposal, soil erosion, landscape deterioration, and pollution. Artisanal gold mining is the physical extraction of gold from open pits using hand tools, followed by washing, drying, and crushing of the ore. Open cast pit tailings are disposed

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of without regard to suitable laws regarding the prevention or reduction of ionization and other sources of dangerous radiation to human life (Friis, 2015). As a result of this discovery, mining has been recognized as one of the potential sources of exposure to naturally existing radioactive elements. Consequently, baseline investigations must be conducted prior to the initiation of artisanal operations and the following "ionizing radiation sources" that will emerge from these activities. Additionally, these radiation sources can be found in a broad variety of occupational contexts, such as healthcare facilities, research institutions, nuclear reactors and their support facilities, nuclear weapon production facilities, and other manufacturing settings, among other places. If these sources are not effectively regulated, they can pose a significant health risk to the employees who are exposed to them. For instance, radium poisoning occurred among women who painted watch dials in the early twentieth century, which was notable in history (Darko et al., 2010).

Other personnel who might be exposed to ionizing radiation include physicians and other health professionals as well as those working in some manufacturing and service industries, defense installations, research institutions, universities, and nuclear power facilities. Industrial applications of ionizing radiation include the checking of welds and joints, security inspections, sterilization of foods and other materials, and analytic procedures (Kinyua et al., 2011). Approximately 800,000 and more than 2 million employees worldwide are exposed to ionizing radiation in nuclear and medical facilities, respectively (Friis, 2015). However, less obvious exposures to ionizing radiation occur in underground mines (e.g. from radon gas exposures), even though levels of radiation can be lowered through adequate ventilation. Another less recognized exposure is that involving aircraft pilots and cabin personnel to cosmic rays (Doyi et al., 2013). The total amount of exposure in this group is correlated with the duration of a flight and is greater at higher altitudes than at lower altitudes. For example, on a long-distance flight between Paris and San Francisco, the estimated effective dose of cosmic radiation is 0.0 849 mSv (Doyi et al., 2013).

Table 1: Dose Limits of Ionising Radiation

Persons	Effective Dose[a] (mSv)		Equivalent Dose[b] (mSv)	
	In a Year	In a Year, Conditional	For the Lens of the Eye	For the Skin (Averaged for Any 1 cm' Area of Exposed Skin) and for the Hands, Forearms, Feet, and Ankles
Workers and apprentices aged 18 years and over	20	50 (limited to 100 mSv during the subsequent 5 years)	150	500
Apprentices aged 16-18 years	6	-	50	150
Members of the general public and apprentices under 16 years old	1	The dose of 1 mSv may be exceeded on the condition that the average for the subsequent 5 years does not exceed 5 mSv	15	
Pregnant woman Foetus	A pregnant woman may not be employed under conditions that could cause the foetus to absorb an effective dose exceeding 1 mSv. A breastfeeding woman may not be exposed to internal and external contamination			
Effective dose: The sum of equivalent doses absorbed from external and internal contamination, determined with the use of appropriate organ or tissue weighting factors, which illustrates exposure of the whole body.				
Equivalent dose: Dose absorbed by a tissue or organ, determined on the basis of ionising radiation type and its energy.				

Source: (Koradecka, 2010)

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Results in table 4 indicate safe limits as advocated by World Health Organization Standards and presented in the Handbook of Occupational Safety and Health (Koradecka, 2010).

2.0 Materials and methods

2.1 Study area

The study was conducted in Nyanza and Western Kenya, which have gold deposits (Figure 1).

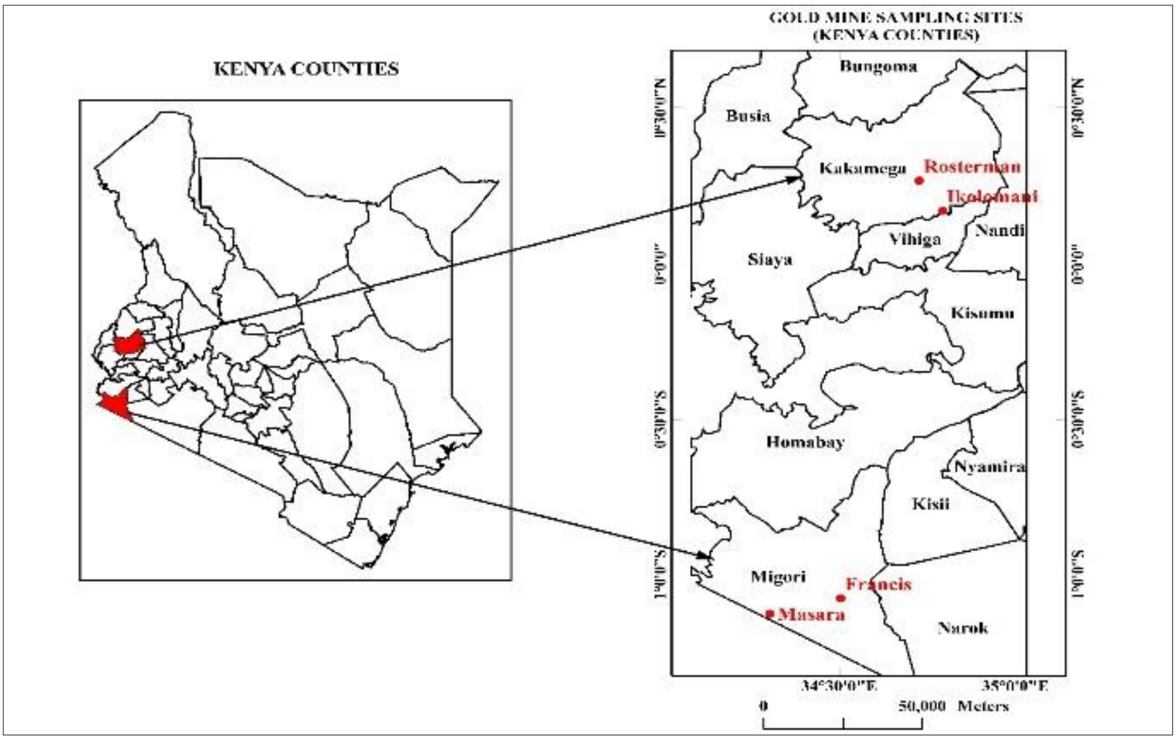

Figure 1: Nyanza- Migori and Western – Kakamega Liranda corridor, Ikolomani

2.2 Methodology

Six sites were randomly selected in the Western and Nyanza regions. These were located using the global positioning system model GPS-GARMIN. Sixty (60) artisanal gold miners' were selected using purposive sampling. GMT, model PHYWE, was used to detect ionizing radiation. TLB supplied by d-Orbital Limited Company was distributed to the 10 miners at each site. Effective dose organ exposure was assessed monthly for radiation exposure and a control sample away from mining activities within the same geographical region. Personal exposure levels were measured and recorded from the TLB, from which a UD-716AGL radiation analyser was used for reading.

3.0 Results and discussions

Occupational radiation activities at gold artisanal mining sites

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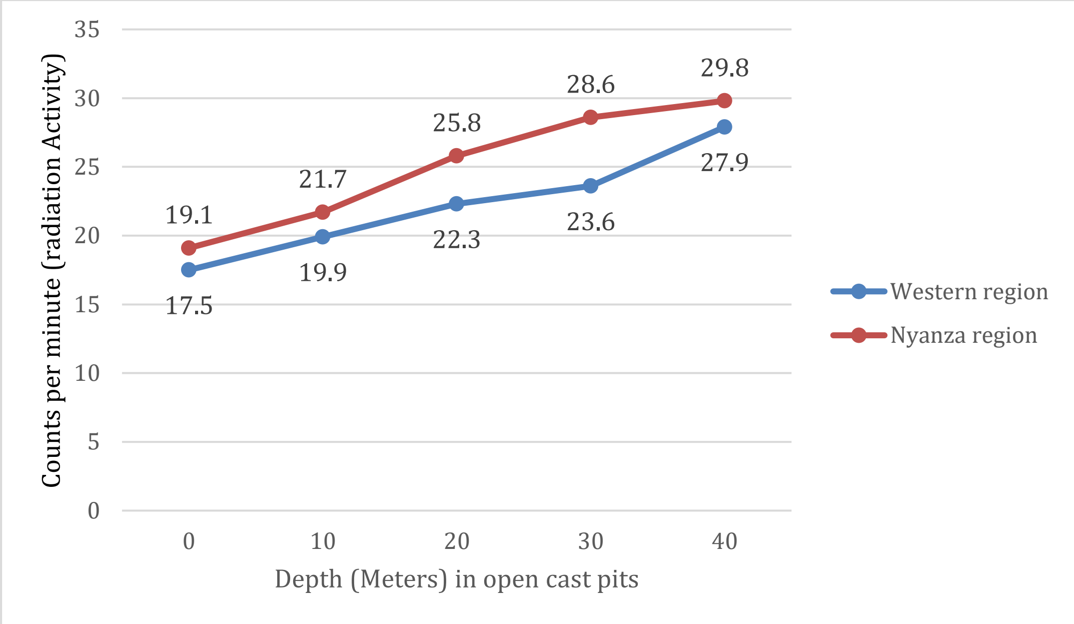

Figure 2: Occupational radiation activities at gold artisanal mining sites

Results reveal an increase in counts per minute with a depth ranged from 19.83 ± 3.87 to 27.83 ± 2.10 and a mean of 23.62 ± 5.17 as shown in Table 1. Sites in Nyanza were found to have slightly higher cpm than those in the western region. This agrees with findings reported by Wanyama et al., (2020) and Buyela et al., (2017) on tailing waste from gold mining sites and agricultural activities, respectively. The variation of natural radioactivity levels at different sampling sites was due to the variation of concentrations of radionuclides in the geological formations in quarries (depth) (Kinyua et al., 2011), which agrees with the findings in table 2.

Table 2: radiation levels (counts per minute) at artisanal gold mines (n)

	Range	Mean	Std. Deviation
Western region	17.50 - 27.90	22.24	3.9
Nyanza region	19.10 - 29.80	25.00	4.5
Valid N (list wise)			

Table 3: Chi-Square Tests for occupational radiation activities at gold artisanal mining sites (Western and Nyanza regions).

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	20.000[a]	16	.220
Likelihood Ratio	16.094	16	.446
Linear-by-Linear Association	3.612	1	.057
N of Valid Cases	5		

a. 25 cells (100.0%) have expected count less than 5. The minimum expected count is .20.

From table 3, there was no significant difference between the two mining sites on exposure to

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ionizing radiation.

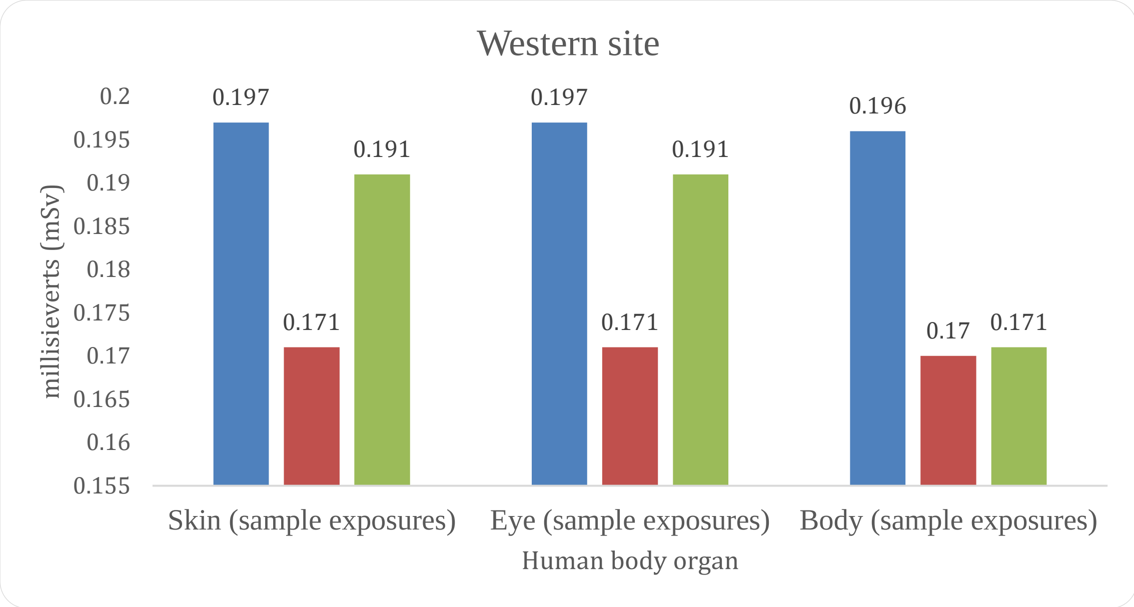

Figure 3: Effective dose exposure of human organs in artisanal gold miners

Figure 3 shows the results of the study, which showed that artisanal gold miners in the Western Kenya region are exposed to ionizing radiation.

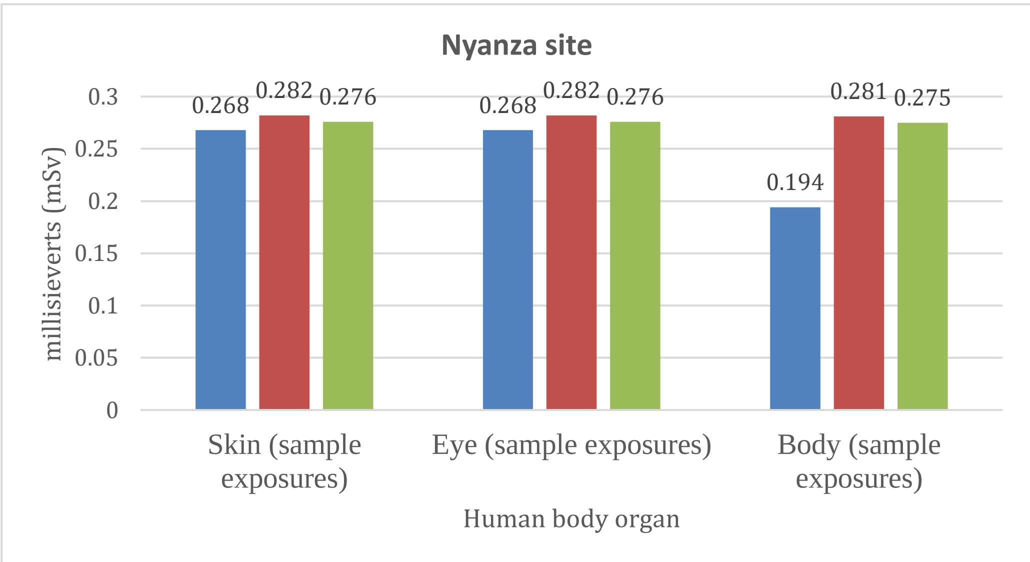

Figure 4: Effective dose exposure of human organs in artisanal gold miners

The results in figure 3 indicate that artisanal gold miners in the Nyanza region are also equally exposed to ionizing radiation.

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Table 4: Radiation eye skin body chi square tests at the two mining sites

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.000[a]	1	.157		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	2.773	1	.096		
Fisher's Exact Test				1.000	.500
Linear-by-Linear Association	1.000	1	.317		
N of Valid Cases	2				

a. 4 cells (100.0%) have expected count less than 5. The minimum expected count is .50.
b. Computed only for a 2x2 table

From the results in table 4, there was no significant difference in occupational ionizing radiation exposure to organs (eye, skin, and body) between the two mining sites (i.e., the Western region and the Nyanza region). These results agree with those of Wanyama et al. (2020) that the tailing samples recorded doses and radiological indices below the world average permissible values. This implies that the radiation exposure to the miners and general public due to tailing wastes at Rosterman gold mine poses no significant health risk. If the exposure to health risks were reduced or minimized, then the conditions of the work environment would improve for employees (Oluoch et al., 2017; Buyela et al., 2022).

4.0 Conclusion and recommendation

From the research findings, there was exposure to ionizing radiation and effective dose exposure to skin, eyes, and body as indicated by the GM tube detector, although these were within safe limits.

The researcher recommends continuous monitoring of environmental ionizing radiation and effective dose exposure to miners throughout artisan gold mining in the country.

5.0 Acknowledgements

5.1 Funding

None

5.2 Presentation of the study, findings, and a portion of the work

These preliminary findings were presented in a paper at the 16th edition of the JKUAT Scientific, Technological, and Industrialization Conference, held from March 24 to March 25, 2022 at Jomo Kenyatta University of Agriculture and Technology in Kenya. Sub-themes include water, energy, the environment, and climate change. The abstract for this paper may be found at https://drive.google.com/file/d/1pCiWvu_euU7VfS-_Q4krXYViWSeFelml/.

5.3 General statement

Within the "*Occupational exposure risk to radiation*" analysis, research management was

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necessary to complete this project successfully. The authors acknowledge the following site supervisors: Lucas Onyango, John Nyongesa, and Micahel Oteino (Rosterman Kakamega). In addition to the site representatives for Migori county, Jacod Alunga, Fred Adongo, Bernard Ogolla, and George Kabambe.

5.4 General acknowledgement
The authors are grateful to the managers of artisanal gold mining sites at Liranda corridor and Ikolomani (Rosterman), Kakamega County, Western Province, and Masara and Francis sites in Migori, Nyanza Province, Kenya for allowing and facilitating the conduction of research throughout the period and their assistance whenever needed and called upon.

In addition, the sixty (60) artisanal gold miners' selected using purposive sampling, upon signing a consent form that informed them about the nature of the research, were given thermoluminescent dosimeter badges (TLB) 802A that were used to record personal radiation exposure levels. Also, d-Orbital Limited, a company that provided UD-716AGL badges used to read the radiation levels from the TLB, conducted analysis of the data, and proved the data result.

5.5 Declaration of interest
Ethics approval for the analysis was issued on September 20th, 2019, Ref: JKU/2/4/896b, issued by Jomo Kenyatta University of Agriculture and Technology ERC.

The writers' opinions, assessments, knowledge, and conclusions in this paper are exclusively their own. The current study fulfills the requirements for the degree "PhD in Occupational Health and Safety."

5.4 Conflict of interest
No conflict of interest declared.

6.0 References
Buyela, C., Njogu, P., Kikuvi, G., Kamau, J., Mburu, C., & Westervelt, D. (2022). Occupationalsafety and health hazards in artisanal gold mines in Western and Nyanza region, Kenya. Journal of Agriculture Science & Technology, 21(2), 55–65.

Buyela, C. W., Mburu, C., & Njogu, P. (2017). Occupational Safety and Health Practices In Agricultural and Livestock Research Organisations, Western Kenya Region. International Journal of Environmental and Agriculture Research, 3(8), 09–15.

Darko, E. O., Faanu, A., Awudu, A. R., Emi-Reynolds, G., Yeboah, J., Oppon, O. C., & Akaho, E. H. K. (2010). Public exposure to hazards associated with natural radioactivity in open-pit mining in Ghana. Radiation Protection Dosimetry, 138(1), 45–51.

Doyi, I., Oppon, O. C., Glover, E. T., Gbeddy, G., & Kokroko, W. (2013). Assessment of occupational radiation exposure in underground artisanal gold mines in Tongo, Upper East Region of Ghana. Journal of Environmental Radioactivity, 126, 77–82.

Friis, R. H. (2015). Occupational Health and Safety for the 21st Century. 400.

URL: https://ojs.jkuat.ac.ke/index.php/JAGST
ISSN 1561-7645 (online)
doi: 10.4314/jagst.v21i3.3

Kinyua R., A. V. O. and O. R. M., Kinyua, R., Atambo, V., & Ongeri, R. (2011). Activity concentrations of 40 K, 232 Th, 226 Ra and radiation exposure levels in the Tabaka soapstone quarries of the Kisii Region, Kenya. African Journal of Environmental Science and Technology, 5(9), 682–688.

Koradecka, D. (2010). Handbook of Occupational Safety and Health. In Handbook of Occupational Safety and Health. CRC Press.

Oluoch, I., Njogu, P., & Ndeda, J. O. H. (2017). Effects of Occupational Safety and Health Hazards' Exposure on Work Environment in the Water Service Industry within Kisumu County - Kenya. IOSR Journal of Environmental Science, Toxicology and Food Technology, 11(05), 46–51.

Wanyama, C. K., Makokha, J. W., & Masinde, F. W. (2020). A Radiological Survey in Tailings: A Case Study of Rosterman Gold Mine, Western Kenya. OALib, 07(05), 1–9.

URL: https://ojs.jkuat.ac.ke/index.php/JAGST
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