ORIGINAL RESEARCH ARTICLE

Occupational safety and health hazards in artisanal gold mines in western and Nyanza region, Kenya

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ABSTRACT

Artisanal and small-scale gold mining (ASSGM) has experienced rapid growth due to mineral value and increasing poverty level in western and Nyanza regions in Kenya. The sub-sector has hazardous tasks occasioned by chemical exposures to such substances as mercury, physical strain and repetitive movements associated with extractive tasks challenge which vary from region to region and site to site. This paper reports findings of a study conducted on ASSGM in Kakamega (Roster mine and Ikolomani) and Migori (Masara-Suna West and Francis - Suna East) counties to assess workplace safety, health risk and good health practice among a population of one thousand four hundred (1400) miners and non-miners to identify and determine levels of health hazard in the sector. Descriptive cross-sectional design that involved stratified sampling technique with three broad stages was used: dividing mining and non-mining population in sub-groups (miners, foremen/supervisors, and head of households) at sites in administering to them research instrument using a simple random technique. Levels of airborne particulate matter ($PM_{2.5}$ and PM_{10}) were determined both at mining sites and away from mining sites using low cost monitor sensor (PA-11-SD Purple air sensor). The low-cost monitor sensor data was corrected using collocational data obtained using a continuous particulate monitor (BAM 1020) reference monitor in a similar location. SPSS version 25.0 was used to analyse qualitative data. The study found that common sources of hazards included handling elemental mercury with bare hands during amalgamation and exposure to fumes during refining raw sponge-like gold. Aaverage 24-hour variation cycle for ($PM_{2.5}$ and PM_{10}) was 117.11±14.47 and 195.18±15.35 µg/m^3 in ambient air respectively at all mining sites. Histograms were used to present frequency distribution of variations for ($PM_{2.5}$ and PM_{10}) from mining activity. The average humidity and temperature variations of artisanal gold mining were in the range of (45-35) percentage (% RH) and (26-28)^{0}C respectively. The study concluded that there were high risk cycle exposures to airborne particulate matter contaminants at artisanal gold mining sites as compared to non- mining sites. The study recommends that the county government should give priority to developing safe guidelines to ASSGM. The central government should also come up with guidelines on Occupational Safety and Health in

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artisanal gold mining to facilitate compliance with OSH requirements in the sector and offer effective participative training.

Keywords: Occupational safety and health, hazard, ‘$PM_{2.5}$ and PM_{10}, miners

1.0 Introduction

It is estimated that globally, 13 million people depend on artisanal gold mining for their livelihood and that majority of these people are in developing countries (Donkor et al., 2011). Artisanal and small-scale gold mining (ASSGM) is defined as mining by individuals, groups or cooperatives with minimal or no mechanization often in the informal sector (Greg et al., 2018) . This is an important economic activity in many developing countries across Africa, Asia and South America. There are several gold deposits present in Kenya, which include; Migori (Suna west and East) and Kakamega (Rosterman and Ikolomani- Liranda corridor) (Mutono, 2016). The small-scale miners employ traditional techniques for mineral extraction and usually operate under hazardous, labor intensive, highly disorganized and illegal conditions (Greg et al., 2018).

In order to free gold particles, the miners add mercury to the ore forming a mercury-gold amalgam. The amalgam is then cleaned with water and later roasted in high temperatures to release the gold from the mercury (Donkor et al., 2011). Approximately 300 tons of volatilized mercury is released annually to the atmosphere in form of aerosol particulate (pollution) (Suvarapu et al., 2013). Exposures to mercury, even in small quantities, are associated with serious health problems including complications during fetal development and early life (Greg et al., 2018). The inorganic mercury released to the environment may be converted by microbial activity to organic forms of mercury, like methyl-mercury, a potent neurotoxin, which damage the central nervous system and is especially toxic to fetus (International (Donkor et al., 2011), hence the need to identify and assess levels of aerosols particulate at every artisanal mining sites.

2.0 Materials and methods

2.1 Study area

The study was conducted in Migori (Suna West and East) in Nyanza- globally located at 1° 1' 59" S, 34° 19' 59" E) and Kakamega (Rosterman and Liranda corridor-Ikolomani) in Western Kenya globally located at 0°17.569N, 34°39.812E), which are major explored gold deposited regions;

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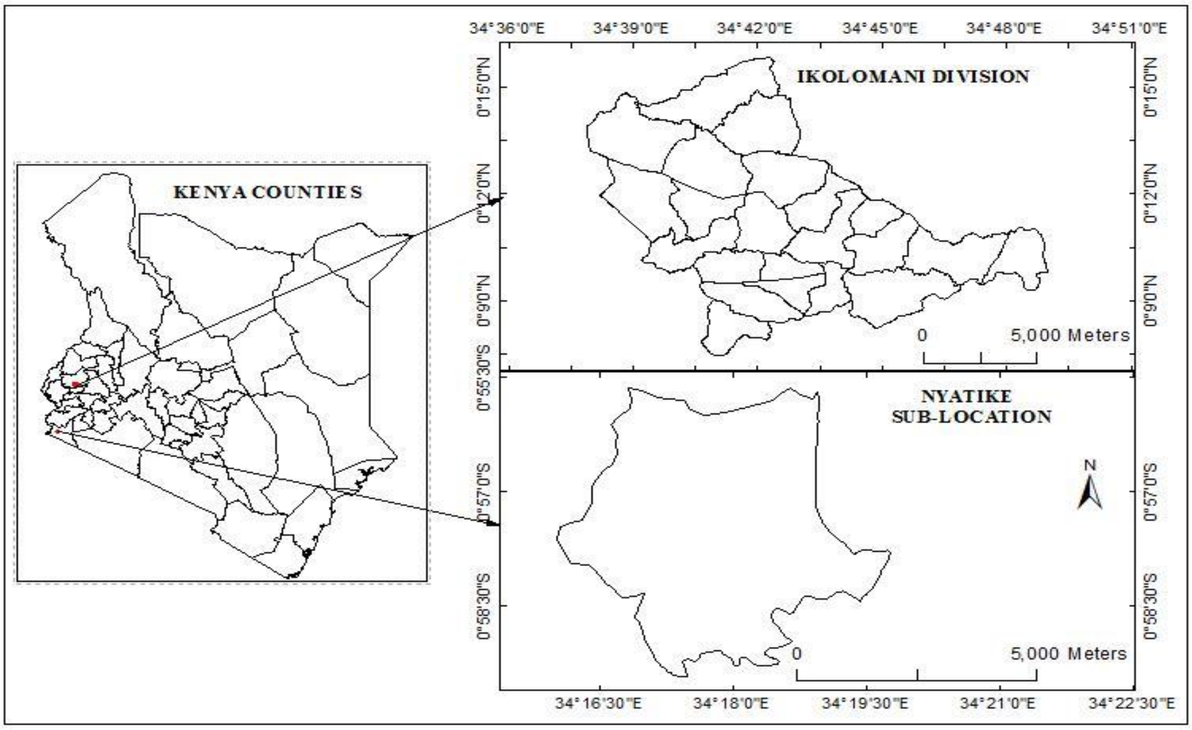

Figure 2.1: Nyanza- Migori and Western – Kakamega, Liranda corridor-Ikolomani

2.2 Study design

Descriptive cross -sectional design that involved stratified sampling technique was applied in the study. This involved experimental set-ups using the Purple air sensor, structured questionnaires on health hazards, checklist, photographs and observation tools to collect the required data. The questionnaires were hand delivered to the respondents. Checklists and observation were used to assess the location, processes, operating environment, structure and related factors (hazards) at the workplace. Purple air sensor processor (PA-II-SD) was set at an average breathing height of a worker facing against wind direction. At each site, measurements were taken between 07:30 hrs and 17:30 hrs local time, for five non-consecutive weekdays.

2.3 Analysis of data

The Statistical package for social scientists Version 25.0 (SPSS) software was used to analyze responses from the questionnaires from respondents. Pilot study was conducted after which the questionnaires were edited to completeness, relevance and accuracy. The final data was collected and then coded to enable the responses to be grouped into categories for both closed and open-ended questions. The statistical data analysis was done using descriptive statistics and visualized using bar charts, tables, frequencies. Inferential analysis conducted for goodness of fit and contingency analysis.

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3.0 Results and discussion

3.1 Common sources of health hazards in four artisanal gold mining sites

Sources of hazards and proposed control strategy measures for six major artisanal gold mining stages (i.e., Ore extraction, crushing/milling, concentrating, amalgamation ,heating, and refining raw sponge-like gold) (table 3.1);

Table 3.1: Sources, and proposed Control of Hazards at mining sites

Activity	Hazards	Source	Proposed Control Measures
Ore extraction (tunneling and dredging)	Machinery	Emissions	Proper maintaining of machines
Processing/crushing and milling	Machinery	Emissions	Proper maintaining of machines
	Dust	Illness, respiratory diseases	Use of masks and training
	Chemicals	Ingestion, inhalation ,dermal exposures	Training and use of PPEs
Concentrating (washing and panning)	Chemicals	Ingestion, inhalation dermal changes	Training and use of PPEs
Amalgamation (use of elementary mercury)	Chemicals	Ingestion, inhalation dermal changes	Training and use of PPEs
Burning using pressure touch or jikos	Tools	Injury from tools	proper use of tools
	Chemical/fumes	Inhalation of chemicals	Training and use of PPEs
	Small rooms	Small confined rooms	ventilation installation
	Chemicals/fumes	Inhalation of chemicals	Training and use of PPEs
	Small rooms	Small confined rooms	Improved ventilation
Refining sponge gold (removal of impurities)	Chemicals / fumes	Inhalation of chemicals	Training and use of PPEs

The respondents from the four mining sites Kakamega (Roster mine and Ikolomani) and Migori (Masara-Suna West and Francis - Suna East) reported sources of health hazard as follows; from Machinery (55%), Lifting weight (41%), fall from depth (38%); tools (24%); attack from animals (17%); exposure to dust (3%).

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At the four artisanal gold mining sites, miners acknowledged that inhalable particulate matter contribute to ill health issues with total agreement of 97% of the population as shown in figure 3.1

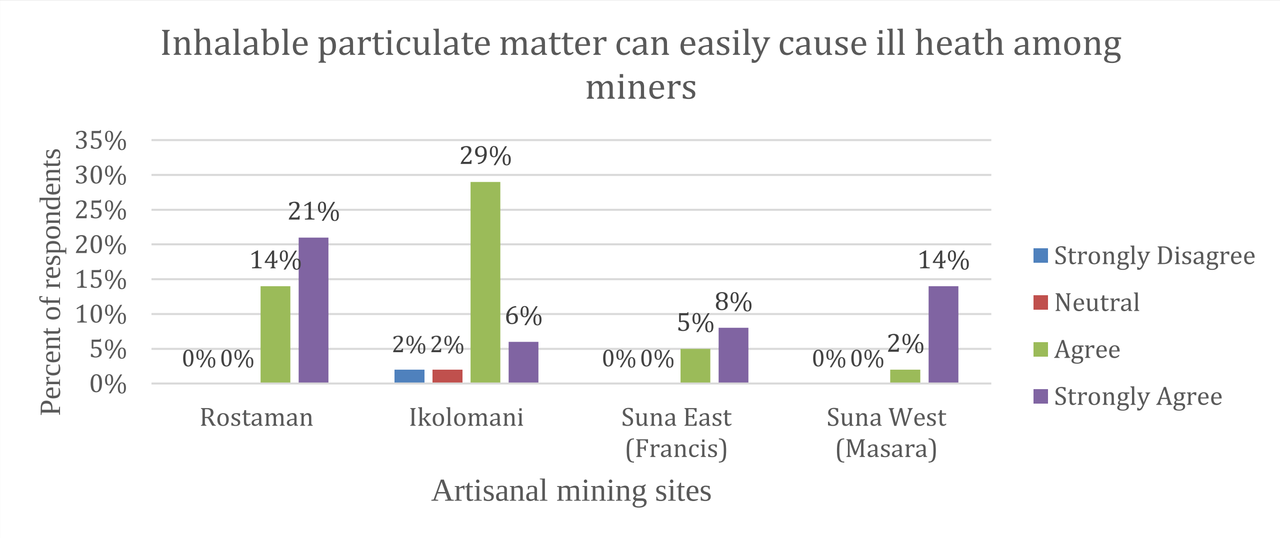

Figure3.1: Perception that inhalable particulate matter (PM) lead to ill health

The study is in line with previous study by (Utembe et al., 2015) that identified hazards at artisanal mining sites in South Africa. Exposure to inhalable dust (chemical hazard) is a risk factor for many respiratory diseases among miners (Aduwo, 2012).

3.2 Inhalable particulate matter ($PM_{2.5}$ and PM_{10})

Particulate matter is a mixture of solid particles and liquid droplets found in the air. The particle pollutants comprises either $PM_{2.5}$: fine inhalable particle with a diameter that are generally 2.5 micrometer or smaller; or PM_{10} which are inhalable particles that are generally 10 micrometer or smaller.

Four sampling points were selected based on where the mining activities were concentrated as reference points. The low-cost monitor sensor data was validated using collocational data from a continuous particulate reference monitor (BAM 1020). The background measurement (BG) point was set away from mining activities but within the same location and monitoring conducted using a portable Purple-air sensor (PA-II-SD).

The purple-air monitor was set at an average breathing height of a worker facing against wind direction. At each site, measurement was recorded between 07:30 hours and 17:30 hours local time, for five non-consecutive weekdays.

The average daily cycle of the PM at mining sites were as follows: $PM_{2.5}$ = ranged from (21.06 to 121.90) µg/m^3 with average output being 117.11 µg/m^3 +14.47 µg/m^3, while PM_{10} = ranged from (35.91 to 312.28 µg/m^3) average output being 195.18+15.35 µg/ m^3). The 24-hour cycle variation for $PM_{2.5}$ and PM_{10} was high within the artisanal gold mining sites as compared to

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results from sites away from artisanal gold mining sites where $PM_{2.5}$- ranged from (78.07 to 156.14) with average cycle output of (93.68±25.92 µg/m^3) and PM_{10}= ranged from 93.68 to 187.37 with average daily cycle of (93.68±28.26 µg/m^3)

The average range of temperature variation at the four gold mining sites was (26-28) ^{o}C with its average Humidity range being 45 to 60 % (RH) grams of water vapor per cubic meter volume of air**.** This study agrees with another study conducted in Nairobi and reported in Mutua et al., (2016) in which PM_{10} and $PM_{2.5}$ are at high concentrations (respirable particulate matter) above the permissible levels recommended by EPA and EMCA. The profile of airborne particulate matter (PMs) at Kakamega mining sites as shown in figure 3:

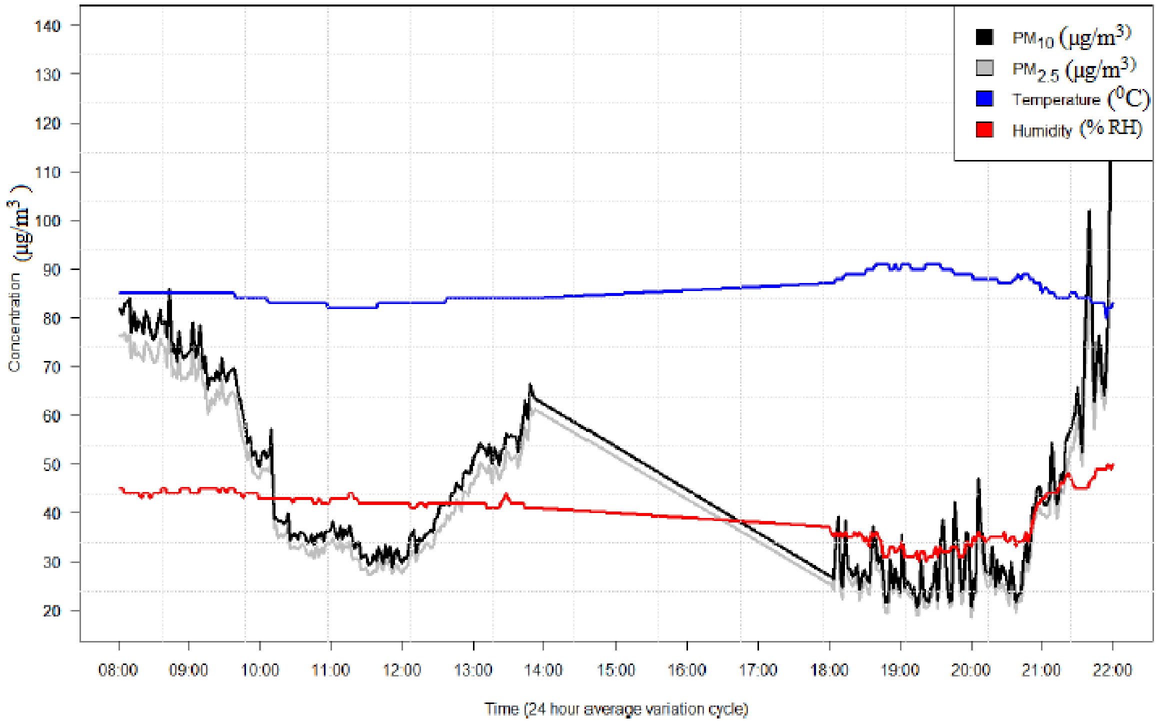

Figure 2: Levels of concentration in µg/m^3 in for $PM_{2.5}$ and PM_{10} at site1 (Kakamega)

Visual interpretation of numerical data trends at Kakamega sites by use of histograms showing high variations cycles at mining sites ($PM_{2.5}$ and PM_{10})

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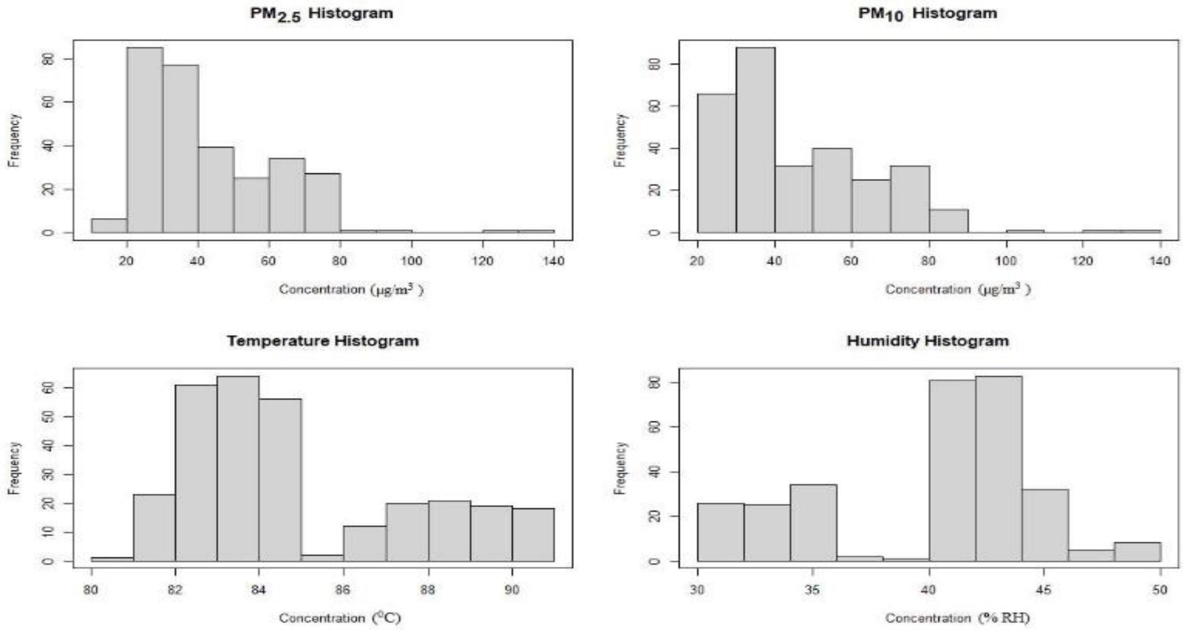

Figure 3: PM$_{2.5}$ and PM$_{10}$ concentration levels in ^{0}C and percentage (% RH) for Temperature and Humidity variation (Kakamega) respectively

The profile of airborne particulate matter (PMs) at Migori mining sites as shown in figure 5:

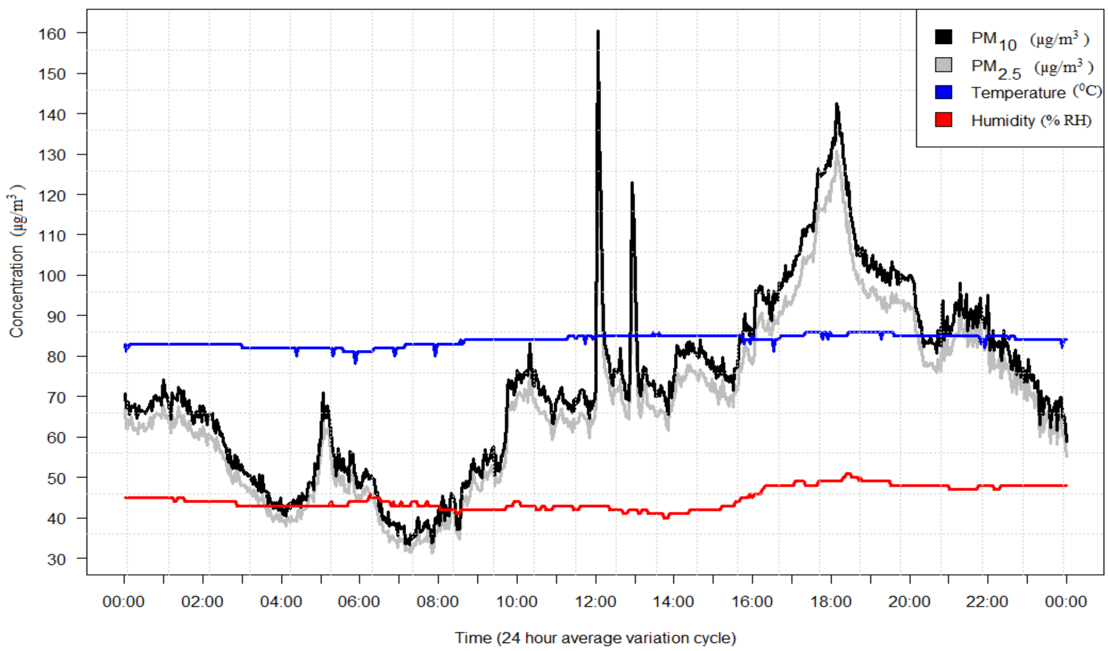

Figure 4: Level of PM$_{2.5}$ and PM$_{10}$ concentration in µg/m^3 at mining site 2 (Migori)

Visual interpretation of numerical data trend at Nyanza-migori sites by use of histogram showing high cycle variations for (PM$_{2.5}$ and PM$_{10}$)

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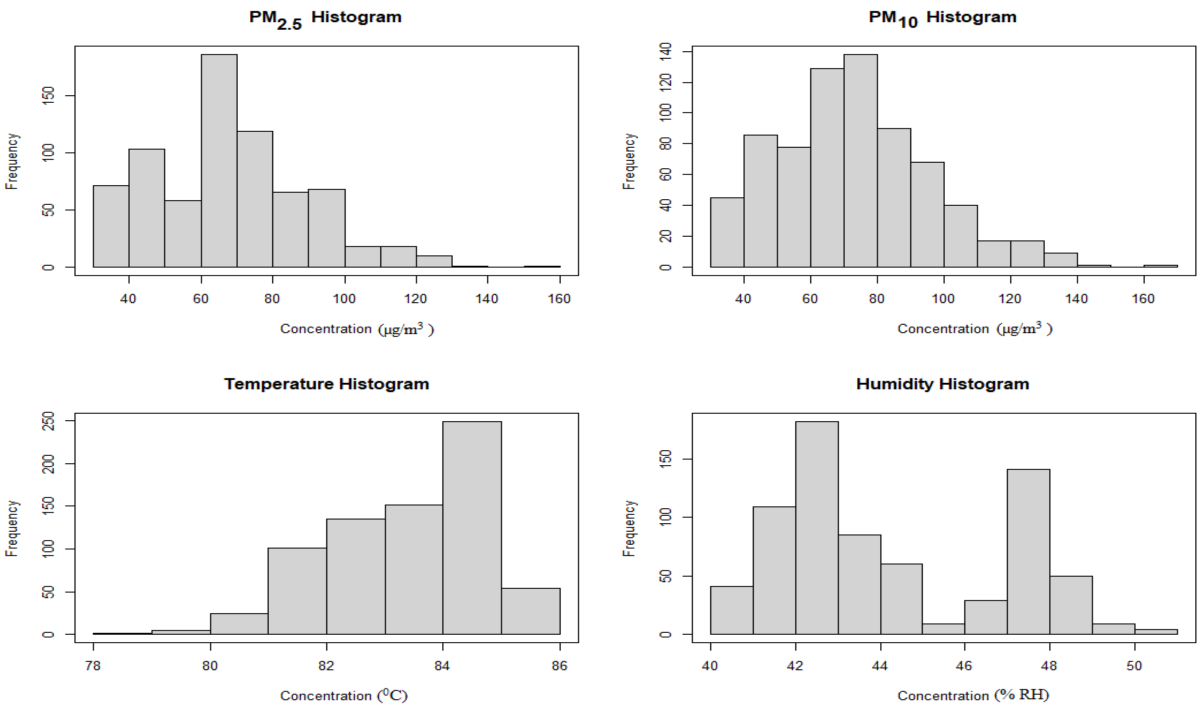

Figure 5: $PM_{2.5}$ and PM_{10} analysis, Temperature and Humidity concentration in (^0C) and percentage (% RH) for Temperature and humidity respectively (Migori)

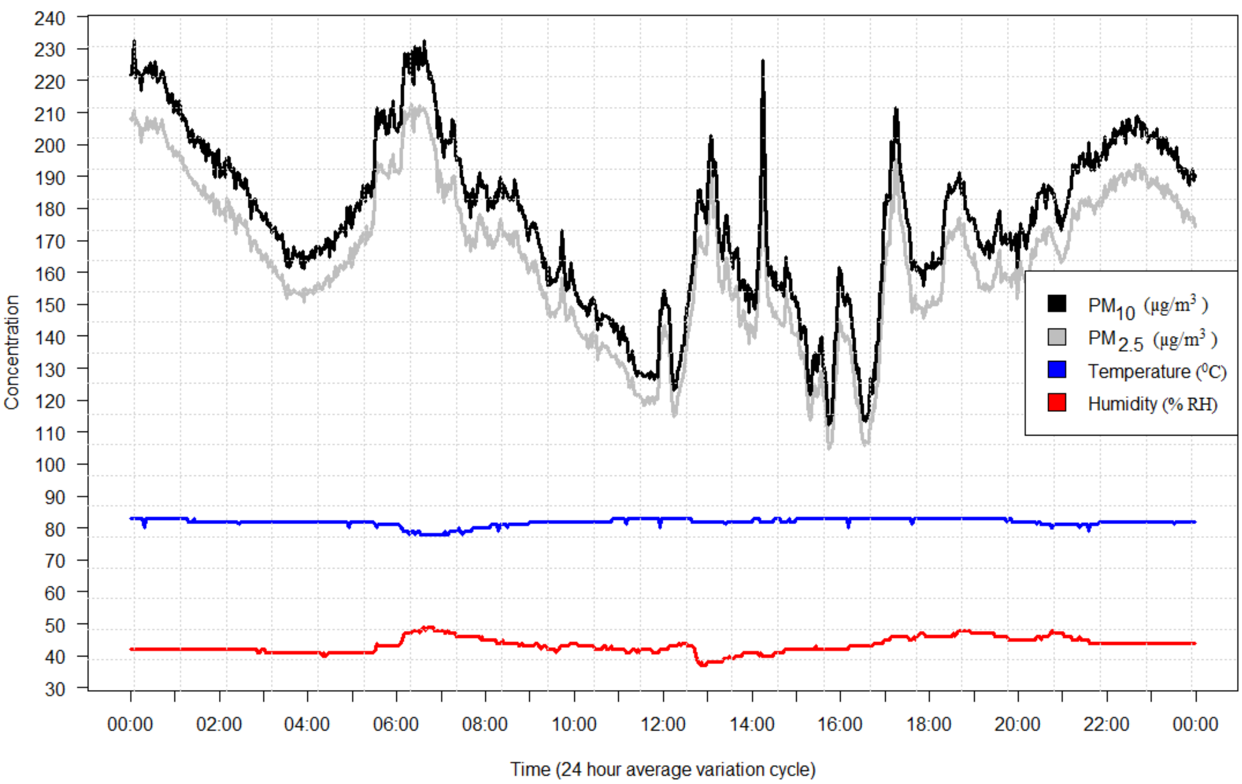

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Figure 6: Level of $PM_{2.5}$ and PM_{10} at site 3 (away from mining Site for comparison)

Visual interpretation of numerical data away from mining sites by use of histograms showing trends with more less cycle variations at sites ($PM_{2.5}$ and PM_{10})

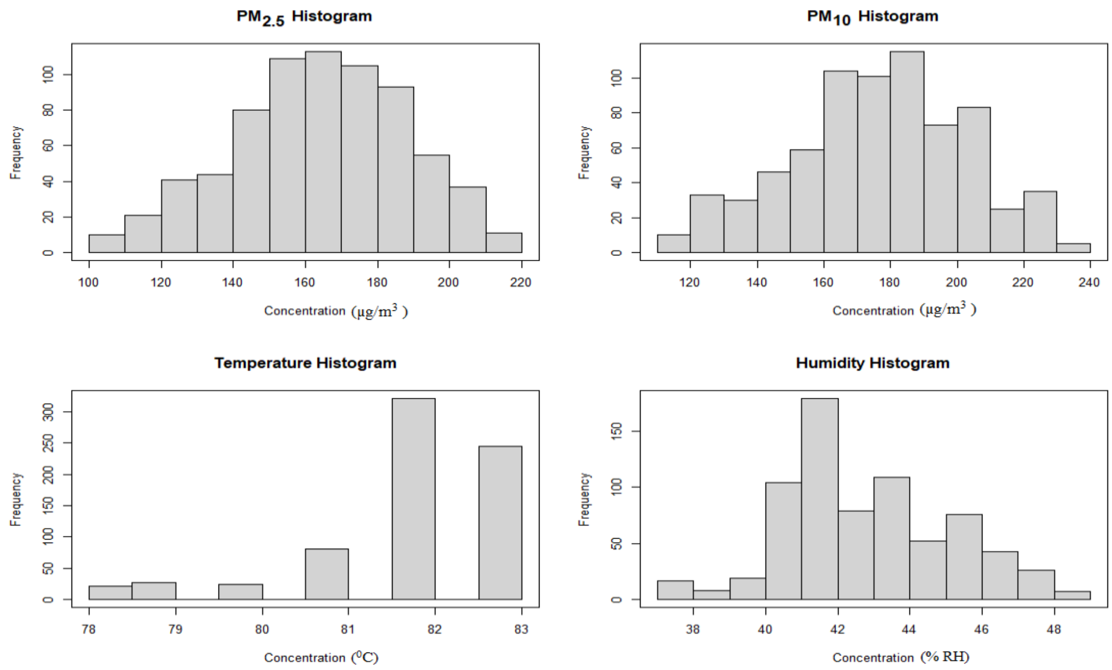

Figure 7: $PM_{2.5}$ and PM_{10} analysis, Temperature and Humidity variation (Bungoma)

Table 2: Correlation analysis of Mining sites and away from mining sites

		Kakamega (Rostaman)		**Nyanza (Migori)**		**Away from mining site**	
		pm 2.5	pm 10.0	pm 2.5	pm 10.0	pm 2.5	pm 10.0
Kakamega (Rostaman)	*pm 2.5*	1.0000	0.9985	0.4416	0.4604	-0.1421	-0.1140
	pm 10.0	0.9985	1.0000	0.4454	0.4642	-0.1409	-0.1124
Nyanza (Migori)	*pm 2.5*	0.4416	0.4454	1.0000	0.9960	-0.2634	-0.2631
	pm 10.0	0.4604	0.4642	0.9960	1.0000	-0.2776	-0.2760
Away from mining site	*pm 2.5*	-0.1421	-0.1409	-0.2634	-0.2776	1.0000	0.9939
	pm 10.0	-0.1140	-0.1124	-0.2631	-0.2760	0.9939	1.0000

There is a positive correlation in terms of $PM_{2.5}$ and PM_{10} association between mining sites in Rosterman and Migori. There is a negative correlation in $PM_{2.5}$ and PM_{10} between points within mining sites and those away from mining sites. In non-mining sites there is almost constant variation cycles for $PM_{2.5}$ and PM_{10} which poses less risk to human health as compared to mining sites where $PM_{2.5}$ and PM_{10} airborne particulate matter is high and thus requiring interventions. This study is in agreement with another study presented in Hashim et al. (2021) that showed that continued use of the dumpsites/tailings may also gradually pose a risk to air quality.

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The study agrees with implementation recommendations of occupational health and safety interventional model which integrates management practices and OSH at artisanal gold mining sites (Nkolimwa et al., 2019).

4.0 Conclusion and recommendations

Exposure to occupational safety and health hazards was revealed in artisanal gold mining communities in Western and Nyanza regions of Kenya. The high numerical value variations in levels of airborne particulate matter ($PM_{2.5}$ and PM_{10}) at artisanal gold mining sites indicated potential health risks to both Miners and Non-Miners alike.

Table 3: Air quality index

Air Quality Index Levels of Health Concern	**Numerical Value**	**Meaning**
Good	0-50	Air quality is considered satisfactory, and air pollution poses little or no risk.
Moderate	51-100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for sa very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101-150	Members of sensitive groups may experience health effects. The general public is not likely to be affected
Unhealthy	151-200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects
Very Unhealthy	201-300	Health alert: everyone may experience more serious health effects.
Hazardous	> 300	Health warnings of emergency conditions. The entire population is more likely to be affected

Source: (First Environments Early Learning Center, 2017)

Positive indicators of safety levels in the four mining sites is necessary in order to avoid or minimize exposure to hazards from mining activities. Safety sensitization, training, health promotion for process management and safe work practice adoption as interventional model to miners is a good strategy to control health hazard at the mining sites for regulatory compliance to (*The Occupational Safety and Health Act, 2007.*, 2007)

5.0 Declaration of ethical approval for research

Dated 20th September 2019, Ref: JKU/2/4/896b, issued by Jomo Kenyatta University of Agriculture and Technology.

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6.0 Acknowledgements

6.1 Funding

None

6.2 Conflict of interest

The authors declare no conflict of interest.

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