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An investigation into Hazards, Controls and Enhancement of Protective Workplace Practices in Artisanal and Small-Scale Gold Mining in Zimbabwe

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Key Words

Occupational health and safety; workplace hazards and risks; controls; disabling contributing causal factors; comprehensive formalisation; protective health and safety practices; behaviour change; business practices; Know-Plan-Practise-Learn-Act cycle; ASGM; Zimbabwe; Progressive-Miner-Centric-Multi-Stakeholder-Gender-Empowering-Approach

Abstract

Background: Artisanal and small-scale gold mining (ASGM) accounts for more than fifty percent of national gold production, contributing to sustainable livelihood and economic development in Zimbabwe. However, ASGM in Zimbabwe involves semi-mechanised ASM and high-risk underground mining processes with compromised workplace practices. Research on ASGM in Zimbabwe has revealed mercury poisoning, TB, HIV, and accidents. Contrarily, there is little research on preventive workplace practices in ASGM in Zimbabwe. This work, investigates hazards, controls, and enhancement of protective workplace practices in ASGM in Zimbabwe.

Methods: Triangulation and method mixing were applied through cross-sectional survey; risk assessment; in-depth interviews, and focus group discussions. Kadoma and Shurugwi were purposefully selected. The Kish Leslie formula was used to calculate a representative sample. Binary logistic regression analysis was applied for quantitative data. Qualitative data was coded and analysed through thematic analysis. Method mixing was applied during data collection and analysis.

Results: Numerous hazards and risks, lacking effective control measures, and compromised protective measures were confirmed. Mercury pollution, accidents, injuries, HIV, TB, malaria risk, as well as alcohol and drug use, were found. The odds of experiencing health and safety risks increased when exposed to underground mining, long working hours, workplace violence and equipment use. Informal practices such as mining activities within homesteads, underground mining near riverbanks and ASGM activities on agriculture sites were revealed. Disabling causal factors contributing to compromised workplace risk management included human, workplace, ASGM-related and contextual factors. Men were more vulnerable to injuries while women occupied peripheral roles. Proposed risk mitigation layers included formalisation, organisation of protective workplace practices and behaviour change. However, each mitigation layer was characterised by gaps and limitations.

Conclusion: ASGM in Zimbabwe is characterized by, numerous hazards, compromised control measures, disabling causal factors, and shortcomings in risk mitigation. The Progressive Miner-Centric-Multi-Stakeholder-Approach together with the bussiness approach were proposed to enhance protective workplace practices in ASGM in Zimbabwe.

List of abbreviations

ASM: Artisanal and Small-Scale Mining

ASGM: Artisanal and Small-Scale Gold Mining

ASGMers: Artisanal and Small-Scale Miners

FGDs: Focus Group Discussions

HIRA: Hazard Identification and Risk Assessment

IDIs: In-depth Interviews

KPPLA: Know-Plan-Practice-Learn-Act

LSM: Large-Scale Mining

MRCZ: Medical Research Council of Zimbabwe

MMMD: Ministry of Mines and Mining Development

OHS: Occupational Health and Safety

PDSA: Plan-Do-Study-Act

PHSP: Protective Health and Safety Practices

PPE: Personal Protective Equipment

PWP: Protective Workplace Practices

List of publications

Paper A

Singo J, Isunju JB, Moyo D, Steckling-Muschack N, Bose-O’Reilly S, Mamuse A. Hazards and Control Measures among Artisanal and Small-Scale Gold Miners in Zimbabwe. Annals of Global Health. 2022;88(1). DOI: https://doi. org/10.5334/aogh.3621

Paper B

Singo J, Isunju JB, Moyo D, Bose-O’Reilly S, Steckling-Muschack N, Mamuse A. Accidents, injuries, and safety among artisanal and small-scale gold miners in Zimbabwe. International journal of environmental research and public health. 2022;19(14):8663. doi.org/10.3390/ijerph19148663

Paper C

Singo J, Moyo D, Isunju JB, Bose-O’Reilly S, Steckling-Muschack N, Becker J, et al. Health and safety risk mitigation among artisanal and small-scale gold miners in Zimbabwe. International journal of environmental research and public health. 2022;19(21):14352. https://doi.org/10.3390/ ijerph192114352

1. My contribution to the publications

1.1 Contribution to paper A

Paper A on 'Hazards and Control Measures among Artisanal and Small-Scale Gold Miners in Zimbabwe' was published in March 2022. As the candidate I was principal investigator, first author and corresponding author. In addition, I was responsible for concept and proposal development; seeking ethical approvals; data collection and analysis; drafting, developing, editing, and finalising the article. Furthermore, I was responsible for project administration and acquiring publication fee scholarship.

1.2 Contribution to paper B

Paper B on 'Accidents, Injuries, and Safety among Artisanal and Small-Scale Gold Miners in Zimbabwe' was published in July 2022. As the candidate I was principal investigator, first author and corresponding author. In addition, I was responsible for concept and proposal development; seeking ethical approvals; data collection and analysis; drafting, developing, editing, and finalising the article. Furthermore, I was responsible for project administration and acquiring publication fee scholarship.

1.3 Contribution to paper C

Paper C on 'Health and Safety Risk Mitigation among Artisanal and Small-Scale Gold Miners in Zimbabwe' was published in November 2022. As the candidate I was principal investigator, first author and corresponding author. In addition, I was responsible for concept and proposal development; seeking ethical approvals; data collection and analysis; drafting, developing, editing, and finalising the article. I was also responsible for project administration and acquisition of publication scholarship.

2. Introductory Summary

2.1 ASGM in Zimbabwe

Artisanal Small-Scale Gold Mining (ASGM) contributes differing proportions to national gold production, up to 100 per cent, in several developing countries [1]. About 14-19 million people were in ASGM globally in 2014 [2]. In Zimbabwe, gold mining accounts for more than 30% of mineral export [3] from both Large-Scale Mining (LSM) and ASM. In the Zimbabwean context, artisanal and Small-Scale gold mining (ASGM) refers to registered ASGM, consisting of licensed individuals, groups or ASGM companies, as well as informal small-scale and artisanal miners [4] with integration between small-scale, and artisanal miners [5]. Additionally, ASGM operations in Zimbabwe consist of groups of up to 50 workers [4], with an annual production fewer than 15 kgs of gold per annum [6]. At the same time, ASGM is a critical economic driver and a fundamental livelihood source [3, 5, 7-9] with higher and quicker returns than agriculture [9-11]. ASGM is a component of ASM, thus, this work, refers to ASM, and ASGM. In Zimbabwe, ASM (which is largely in gold) informally employs more than half a million people [12], sustaining more than one million [7]. Furthermore, in previous decades ASGM contributed more than 50% of national foreign currency [13] and 62% of national gold production in 2021 [8]. Hence the current national economic target is to increase ASGM gold from 15 to 25 tonnes per annum by 2025 [3]. However, ASGM involves both informal and formal, legal, and illegal mining activities, which are rudimentary or semi-mechanised, often defined by low capital, low production, unskilled workforce, environmental degradation and compromised health and safety [14-18]. Moreover, there is no reference to ASM-specific policy nor guidance on regulation or sustainability of ASM in the mining regulations in Zimbabwe [10, 19, 20]. Consequently, experts argued that comprehensive formalisation of the sector should incorporate ASM Policy, ASM regulatory framework, financing and strengthening of health and safety, and environmental management [5, 10, 19, 21, 22]. ASGM formalisation in Zimbabwe is characterised by registration of: processing centres, gold buying centres and mining claims [4]. Concurrently, the licensing process is associated with limited access, long processes, high costs and inefficiencies in Cadastre System [23]. Apparently, one of the current national targets of the National Development Strategy is developing ASGM Policy by 2025 [3]. Despite positive local and international efforts to fund ASGM [3, 23, 24], access to finance is limited by eligibility criteria requiring licensing and collateral [23, 24]. As a result, scholars and experts have argued that ASGM in Zimbabwe is quasi-formalised [4, 5, 10, 19, 22, 25].

2.1.1 Occupational Health and Safety (OHS): Decent Work and ASGM

In Zimbabwe, reported occupation injuries/illnesses were 22%, with a significant proportion (13%) in LSM in 2022 [26]. However, there is a paucity of data on occupational injuries and illnesses in ASM [27]. In 2020, forty-two; and five-hundred and ninety-two catastrophes were recorded in ASM, in Zimbabwe and universally based on online media data [21]. Concurrently, ASGM employs a more extensive workforce than LSM [28]. Accordingly, in 2022, mining and quarry employed 7.5% in the formal sector (LSM) while the informal (including ASM) sector employed 12%, with 28% of the employed population in the formal sector in Zimbabwe [26]. At the same time, ASGM is characterised by hazardous working conditions evidenced by mine collapses, exposure to respirable chemical dust (including underground dust), mercury intoxication (exposure to other chemicals, e.g., cyanide), heavy lifting, unsafe equipment, poor sanitation and hygiene, chronic stress, violence, and unreported injuries and fatalities among others [1, 7, 29-35]. Studies on ASGM confirm mercury intoxication among ASGMers (including breastfeeding women and children) [2, 36, 37]; tuberculosis (TB) 4%; and HIV, 24 % [38]. Scholars and experts have argued that health risks and sicknesses in ASM are worse than injuries because of overcrowding, indecent shelter, and low standards of water sanitation and hygiene [1, 30-32, 39, 40]. However, ASGM is a potential livelihood source which can reduce poverty and provide gainful employment if adequately managed [21, 41]. Zimbabwe has ratified the Minamata convention on mercury use and developed a National Action Plan to protect human health in ASGM [4]. Additionally, Zimbabwe's National Safety and Health Policy highlights the hazardous nature of mining [42], hence the pivotal role of health and safety in mining [42, 43]. Contrary to industrial mining with defined and established health and safety operations, workplace risk management is usually marginalised in ASGM [44]. Miners in ASGM are therefore exposed to hazardous working conditions with little attention to protective workplace practices [40]. Concurrently, Sustainable Development Goal 8 focuses on decent workplace and economic growth [45]. A study focusing on hazards, controls and enhancement of protective workplace practices in ASGM could guide relevant initiatives for promoting health and safety in ASGM.

2.2 Statement of the Problem

Miners in ASGM are exposed to numerous hazards, including dust, excessive noise, mercury, cyanide, unsafe mining pits, pit flooding, violence, equipment, and confined workplaces, among others [7, 29, 30, 46] with no or compromised protection [1, 21, 31, 33, 40]. However, ASGMers are usually incapacitated to conform to relevant national or international regulations [28]. Additionally, in Zimbabwe, mining legislation has no distinction between industrial and informal mining [20, 43] and is, more adaptable to industrial mining [22]. On the other hand, reported rates of work-related injuries and illnesses in the informal industry surpassed statistics in the formal industry ten and hundred times more in Zimbabwe [47]. Globally, occupational injuries are 6-7 times more in ASM than in LSM [28]**.** In 2019, 31% of ASGMers in Shurugwi and Kadoma (Zimbabwe) had witnessed ASGM-related accidents, while 19% had ever experienced ASGM-related accidents [7]. Furthermore, transitioning to equipment in ASM is associated with increased occupational risks [1, 48]. Contrarily, current initiatives in ASGM, e.g., Mining Industry Loan Fund,[3] and bank loans [23] target increasing ASGM gold production through improving access to equipment with limited or no awareness of protective health and safety practices (PHSP). Conversely, research on mining has shown that management of workplace risks minimises lost time, injuries and health care costs with financial gains [49]. In addition, ASGM in Zimbabwe is mainly hard rock involving underground mining, custom milling, cyanidation and processing plants [4, 11, 23].

Processing plants in ASGM are associated with excessive noise, respirable dust, and chemical pollution (mercury-cyanide complexes) [29, 30, 32, 34, 50]. Furthermore, an increasing number of ASMers are transitioning from artisanal mining to small-scale mining involving ASM mechanisation [7]. Simultaneously, underground excavations in ASM are associated with poor shaft support, poor ventilation, absence of escape routes, increasing the risk of mine collapses, mine flooding and suffocation [1, 7, 33, 51]. Previous studies have confirmed adverse health impacts of dust, mercury, and smoking on lung function among artisanal miners and ASGM communities [52]. ASGMers are a high-risk population for respiratory disorders because of exposure to dust, mercury, overcrowding, confined workplaces, and poor sanitation [31, 34, 38, 39]. Research has confirmed the risk of accidents and injuries, mercury intoxication, TB, and HIV in ASGM in Zimbabwe [4, 36-38, 46]. Furthermore, news headlines on accidents and injuries in ASGM are familiar in Zimbabwe [53], resulting in blame on ASM with no effort on preventive efforts [21]. Nevertheless, accidents are preventable by establishing and addressing causes of near misses and minor incidents [54], while exposure to dust could be reduced through protective work practices such as wet crushing and wet drilling [55]. Thus, health and safety issues in ASGM are preventable [1, 40, 56]. Despite documentation of numerous hazards in ASGM, little research has focused on enhancing protective workplace practices in ASGM in Zimbabwe. Accordingly, a review of studies on OHS in ASGM revealed a gap in management of workplace risks [44]. Accordingly, this work investigates hazards, controls, and enhancement of protective workplace practices in ASM gold mining in Zimbabwe to inform relevant initiatives.

2.3 Conceptual Framework

Contrary to the personal approach, which focuses on individual mistakes, blame and elimination of harmful behaviour, the systematic approach integrates analysis of underlying factors [57]. Accordingly, the systematic framework for managing organisational accidents identifies behavioural, workplace and organisational factors [58] which was modified to incorporate non-human (e.g., equipment) and contextual factors and was found applicable to LSM [59]. The systematic approach for enhancing protective workplace practices in ASGM was developed through the integration of the systematic framework for managing organizational accidents [58], the Swiss cheese model [57] and the Plan-Do-Study-Act cycle [60] Figure 2.4.1.

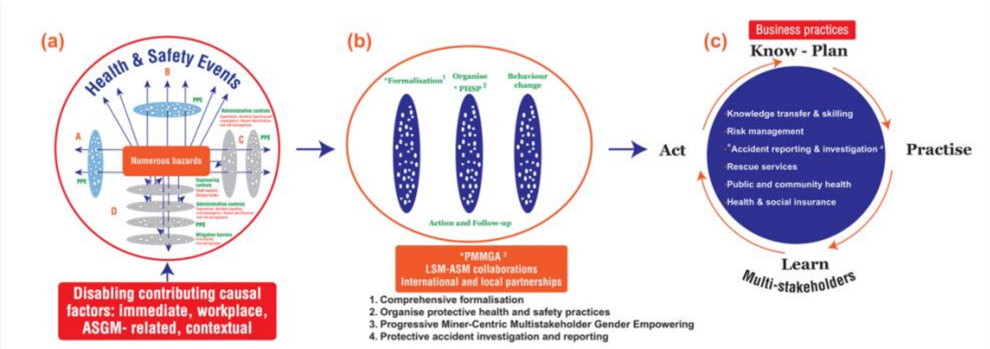

Figure 2.4.1: Systematic approach for enhancing protective workplace practices in ASGM in Zimbabwe modified after [57-63] (a) Numerous hazards and contributing causal factors [58] (See Figure 1(a) [62]pp3 in the context of missing effective control measures (D and C) Figure 1 [61]pp3, compromised PPE use and increased odds of

experiencing health and safety events [63]; *(b) Proposed risk mitigation layers (See Figure 1(b)* [62] *pp3 and the Progressive Miner- Centric-Multi-Stakeholder-Gender-Empowering-Approach (PMMGA) to address barriers to enhancement of protective workplace practices; (c) Application of business practises through Know-Plan-Practice-Learn Act (KPPLA) cycle involving knowledge transfer, continual learning and continual improvement*

The framework focuses on understanding existing hazards and controls through a systematic examination of disabling contributing causal factors, followed by establishing successive defense layers. Comprehensive formalisation, organization of protective health and safety practices and behavior change were the proposed defense layers. However, unlike LSM, ASGM is often associated with, under-capitalisation, intrinsic illegal practices, lack of training and lack of conventional management [1, 5, 10, 22, 28, 41, 64]. Hence the relevance of miner-centric, multiple-stakeholder, community, and public health initiatives in ASGM [40, 48, 64, 65]. The Progressive-Miner-Centric-Multi-Stakeholder-Gender-Empowering-Approach (PMMGA) and the Know-Plan-Practice-Act (KPPLA) cycle were developed to strengthen enhancement of protective workplace practices. The KPPLA cycle was modified after Deming's Plan-Do-Study-Act (PDSA) cycle [60]. PDSA cycle successfully improved OHS at varying levels of various organisations [66] and was applicable in LSM in Zimbabwe [67]. Contrarily, there are gaps in knowledge and training, in ASGM [1, 40, 46, 64]. This study modified the PDSA cycle to Know-Plan-Practice-Learn-Act (KPPLA), to develop a continuous cycle which incorporates knowledge transfer, continual learning, and continuous improvement for implementation of business practices. The integration of models which involve the interaction between hazards, controls, and the contributing factors [58]; protective defense layers [57]; and application of continuous improvement cycle [60] was found appropriate to address study objectives.

2.4 Objectives

The broad study objective was to investigate hazards, controls, and the enhancement of protective workplace practices in ASM gold mining in Zimbabwe, as illustrated in Figure 2.4.1 above. The specific objectives were:

- To identify and understand hazards and controls in ASM gold mining in Zimbabwe
- Assess proportions of accidents and injuries and associated risk factors in ASGM, Zimbabwe
- To assess gendered workplace factors related to women and children in ASGM in Zimbabwe
- To examine disabling causal factors influencing the enhancement of protective workplace practices in Zimbabwe's ASGM
- To evaluate an approach for enhancing protective workplace practices in ASGM in Zimbabwe

2.5 Methods

Data was collected in 2020, from November to December, in Kadoma, Mashonaland West, and Shurugwi, in Midlands, Figure 2.5.1.

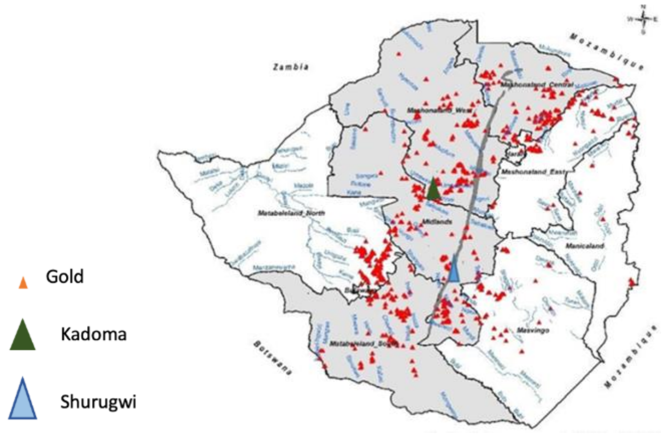

Figure 2.5.1: Study Location [68]

The study location was actively involved in ASGM regarding registered processing centres, a workforce in the sector [4], and ASGM gold production [7, 23] , as illustrated above, Figure 2.5.1. Scholars have proposed the integration of qualitative and quantitative methods to augment understanding of ASGM [40]. This work, addressed the phenomena of hazards, controls, and protective workplace practices from multiple angles (Figure 2.5.2) through triangulation while complementing qualitative and

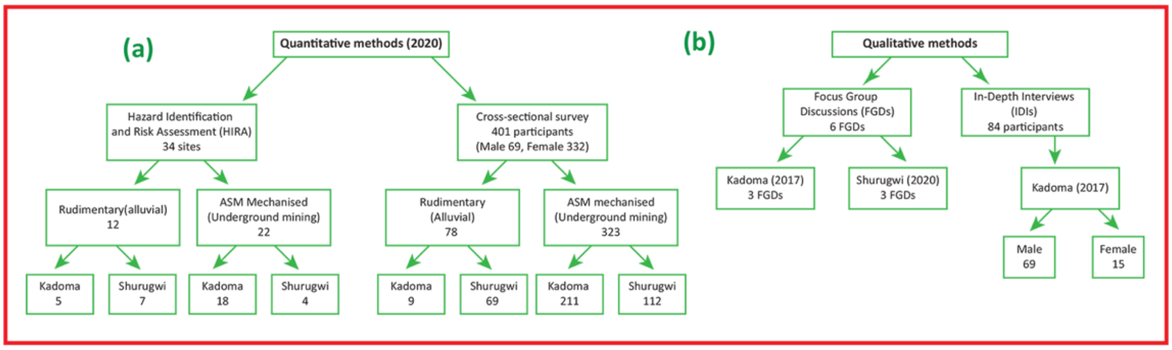

Figure 2.5.2: Research Design: method mixing

qualitative designs through method mixing [69] for a comprehensive understanding of hazards and controls, an in-depth examination of disabling root causal factors contributing to compromised workplace risk management, and a holistic exploration of the enhancement of protective workplace practices. Qualitative data from a different survey conducted in ASGM in Kadoma in 2017 guided and informed the 2020 survey, i.e., triangulation. During the 2020 survey, method mixing was used by integrating quantitative and qualitative methods [69] (Figure 2.5.2). See Chapter 4. Kadoma and Shurugwi were selected purposefully. Simple stratified random sampling was conducted by reshuffling identified sites (names) involved in basic and ASM semi-mechanised methods [61-63]. As indicated in our article, "Thirty-four sites were visited in Mayflower, Brompton, Mudzengi Patchway, Battlefields, Sanyati in Kadoma and Chachacha and Wonderer in Shurugwi" [61]pp4 . Focus group and questionnaire participants were selected randomly from visited sites; see chapter 4 [62, 63]. Data collection instruments were developed and approved together with the research protocol [61-63]. The representative sample size was calculated through the Kish Leslie formula[70]

'$n = Z^2PQ/ d^2$: n = Sample size…; d = Precision/margin of error, which for this study was 5%; Z = Standard normal deviation corresponding to 95% CI = 1.96 P = 0.50 was assumed to obtain sufficient sample size and high precision. Q = 1-P

Substitution: $n = 1.96^2 * 0.5(1–0.5) / 0.05^2 = 3.8416 * 0.25/ 0.0025 = 384.16 \approx 400$.' [71]PP40

Triangulation and method mixing were used for Paper A [63]. The cross-sectional survey (questionnaire) was used for Paper B [61], and appendix 5.1, while qualitative design (FGDs IDIs, Figure 2.5.2) was used for Paper C [62] and Appendix 5.2. A pilot study was conducted with eight miners on two sites in Gwanda and Kadoma in Zimbabwe. The tools were translated into Shona and Ndebele by experienced translators (1 Ndebele translator, 1 Shona translator) and approved by Medical Research Council (MRCZ) together with the research protocol [61-63].

2.5.1 Hazard Identification and Risk Assessment: Chapter 4 Paper A [63]

The standardized HIRA tool [72] (see Appendix 5.3) was modified after a HIRA tool previously used in ASM [73] and tested. A trained team conducted risk assessment through site observations and informal discussions with workers/ miners on site.

As illustrated in our article [63], Risk scores were calculated as,

$$'\boldsymbol{Risk} = \frac{[\boldsymbol{Probability} \times \boldsymbol{Severity}(\boldsymbol{I+P+E+C}) \times \boldsymbol{Frequency}] \times \boldsymbol{100}}{\boldsymbol{500}}'$$ [72]

The risks were profiled for priority on a scale of A-F [72]

Category	**Risk score**	**Action Period**
'A	*75-100%*	*Immediate attention required*
B	*60-74%*	*Attention required in 1 week*
C	*45-59%*	*Attention required in 1 month*
D	*30-44%*	*Attention required in 6 months*
E	*15-29%*	*Attention required in 12 months*
F	*1-14%*	*Attention is required as soon as feasible'* [72]pp2

Risk scores and research findings were moderated, by an ASM association leader and two experienced experts knowledgeable about mining safety and ASGM in Zimbabwe.

2.5.2 Interviewer Administered Questionnaire: Chapter 4 Papers A [63], B [61] and Appendix 5.1

The standardised questionnaire (see chapter 4 Appendix A Paper B [61]) was developed after previous ASM questionnaires [29, 74]. The questionnaire was adapted to the study population and tested [61-63]. A trained team administered questionnaires in the participants' language (Shona) [61, 63]. The exclusion criteria were unwillingness, drunkenness, age under 18 years and less than six months of experience in the sector [61-63].

2.5.3 Focus Group Discussions: Chapter 4 Papers A [63], C [62] and Appendix 5.2

In 2020, focus group discussions were conducted in Shurugwi with male miners, female miners and women (previous miners/partners to ASGMers) [62, 63]. The focus group guide was developed (See Appendix A Paper C and tested. Focus group discussions were conducted in the participant's language and recorded with a Samsung recorder. The FGDs were transcribed into Microsoft word, translated into English, and verified by the translator.

2.5.4 Data from FGDs and In-depth Interviews from 2017 Survey: Chapter 4 Papers A [63], C [62] and Appendix 5.2

Findings were supplemented by 2017 survey data (FGDs and IDIs) [63].

2.5.5 Data Management and Analysis

Missing data was checked at the submission of questionnaires. Data were checked during fieldwork. A research assistant and the principal investigator entered data into the Kobo toolbox and imported the data set into SPSS. The data was cleaned and checked against the original data by two independent assistants. Incompatible and missing values were rechecked. Valid codes not possible for specific variables were used for missing data. Samples of original data, SPSS data sets, codes, outputs tables and graphs were shared with the principal supervisor for quality control. Data sets, summary notes from the in-depth interviews and focus group transcripts are available online.

2.5.6 Ethical Considerations

Ethical clearance and local permission were acquired from the University of Munich Ethics Committee, Medical Research Council of Zimbabwe (MRCZ) (see Chapter 4), relevant community authorities, site leadership (where applicable), and site owners.

2.6 Results

2.6.1 Baseline Assessment (Chapter, 4 Papers A [63], Paper B [61]; Appendices 5.1 and 5.2)

HIRA was conducted on 34 sites, 401 questionnaires were filled, 3 FGDs were conducted in 2020. Data was complemented by 3 FGDs and summary notes of 84 IDIs from 2017. Multiple hazards were confirmed. Electrical, chemical, and equipment hazards were dominant in semi-mechanised ASGM. Unsafe mining pits were associated with flooding, and underground trappings. Informal activities were persistent, e.g., mining in residential areas; mining near riverbanks; and ASGM activities on agriculture sites. Sanitation and hygiene was poor. Land degradation and siltation of the Gadza river was observed. PPE use was the typical and compromised control. Effective controls were missing, e.g., shaft support, wet methods, and use of retorts. Of the 401 questionnaire participants, 178 (45%) reported ever-experienced health and safety events. At the same time, access to health and social security services was rare. The likelihood of experiencing health problems was at least two times more for miners exposed to underground mining. HIV (8% n=21) and TB (7.3% n=28) were reported.

Accidents and injuries were reported at 35% (n= 140) and 25.7% (n= 103). Reported injury risk factors included digging, blasting, being male, underground transportation and working more than 16 hours daily. Underground trappings were among the common accidents. The chance of experiencing injuries after an accident was sixfold [3.7–9.9[P< 0.000]]. Mine inspectors were conducting routine inspections on PPE and registration. FGDs revealed awareness of health and safety protection. There was limited knowledge of recommended shaft spacing. Mine owners expressed interest in health and safety to mitigate losses from injuries and the cost of mercury. Mining regulations (with no distinction between LSM and ASM) with the potential to enhance protective workplace practices were not versatile for ASGM. Men were more vulnerable to accidents and injuries than women. Women had limited access (to licenses, gold, and equipment), and were occupying peripheral roles. Transitioning to processing equipment was substituting women's roles. In addition, women in informal alluvial mining were usually displaced at the discovery of gold.

2.6.2 Enhancement of Protective Workplace Practices (Paper C [62])

Reported disabling factors contributing to compromised protective workplace practices were direct causes, ASGM-related, and contextual factors, while informalities were persistent. Suggested measures included comprehensive ASGM legalisation, organising protective workplace practices and behaviour change. A systematic-causal analysis was proposed for risk assessment and accident investigation despite limitations and gaps in ASGM. Implementation of the Progressive-Miner-Centric-Multi-Stakeholder-Gender-Empowering Approach (PMMGA) and the Know-Plan-Practise-Learn-Act (KPPLA) cycle was suggested to enable enhancement of protective workplace practises in ASGM.

2.7 Discussion

Numerous hazards, ineffective controls, health and safety events and gendered factors were found [29-33, 37, 46, 64]. The mine management and safety regulations, which could enhance protective practices, were incompatible to ASGM [20, 22, 43]. Disablers were confirmed [23-25, 46]. Protective layers were proposed. However, gaps and weaknesses characterised protective layers [40, 57, 58, 64]. Concurrently, there was a willingness among the mine owners to improve protective health and safety practices despite limited capital. The implementation of successive risk mitigation layers through the Progressive-Miner-Centric-Multiple-Stakeholder-Gender-Empowering-Approach and the Know-Plan-Practice-Learn-Act (KPPLA) cycle was proposed to enable the enhancement of protective workplace practices.

ASGM in Zimbabwe is quasi-formalised [5, 10, 19, 22, 25], characterised by disablers [10, 19, 22, 23, 25, 46] which could challenge the KPPLA cycle. The literature, argues for comprehensive formalisation of ASGM, incorporation of ASGM policy, financing, and health and safety [10, 19, 22] which could facilitate enhancement of protective workplace practices. ASGM registration processes were reported as costly, disproportionally affecting women. Concurrently, previous research confirms high licensing costs, inefficiencies in Cadastre System [23] and violence over mining claims [5]. Hence the need to review the registration processes and consider a gender-empowering ASM policy [75, 76]. ASGM associations are well established in Zimbabwe. Thus, ASGM legislation could incorporate relevant protective workplace practices such ASGM policy with an annex on OHS and a provision of OHS roles among ASGM partnerships [65, 77, 78].

Protective workplace practices could be contextualized through consultations [65] involving active participation of miners, local leaders, local community members and ASM associations. In Nigeria, wet practices were enforced in ASM at the community level [55]. At the same time, the broad multi-stakeholder synergies could address gaps in training, financing, planning, and enforcement, with active implementation roles among miners, ASM associations and local community leadership [1, 10, 19, 22, 23, 41, 64]. ASM cooperatives and collaborations could facilitate access to bank loans and security services [1, 23]. Furthermore, LSM-ASM collaborations [41, 79] could support the enhancement of protective practices. On the extreme end, multi-stakeholder initiatives could be challenged by a lack of coordination [7, 11, 22]. Multi-stakeholders could therefore operate in committees [23] through structured coordination [10]. In addition, there is need to empower implementing agencies [1, 10, 62].

The business approach was proposed, site by site, based on the preference to prevent health and safety events while improving economic benefits [49] in long the long-run [58]. In Zimbabwe, ASGM is a driving force for national economic growth [3, 5, 7, 11] and is also conducted by ASM companies, foreigners, and Zimbabweans in diaspora [7]. Besides, this study identified awareness of health and safety practices among the miners which could be attributed to the presence of retired and retrenched LSM workforce [1, 5]. Moreover, there was a willingness to reduce workplace losses associated with injuries and illnesses among mine owners which confirms existing studies [49]. Concurrently, previous studies have revealed that sustainable LSM-ASM collaboration should translate into economic benefits [79]. Thus, KPPLA cycle could be introduced in a business framework, which could facilitate the integration of protective workplace practices in routine ASGM activities [80] with positive impacts on production [10, 19, 22, 25] in long term [58]. The national economic plan on ASGM [3] and ongoing local and international initiatives on ASGM could embrace the business approach and integrate protective workplace practices to increase the Artisanal and small-scale mining gold while promoting protective workplace practices. Finally public and community health initiatives, including TB screening and treatment, HIV and AIDS prevention and management, and malaria prevention and treatment, could also be extended to ASGM communities [1, 40, 48].

2.7.1 Strengths and Limitations

Cross-sectional survey and qualitative data were based on self-responses which was susceptible to response desirability and recall bias. However, hazard identification and risk assessment were also performed. Besides, the study design integrated qualitative and quantitative methods. On the other hand, generalisability could be limited to study areas. At the same time the study areas typified ASGM in Zimbabwe. Furthermore, this study complements ongoing studies on management of workplace risks. In addition, new insights from this study could inform relevant future initiatives in ASGM.

This study did not test the application of the Progressive-Miner-Centric-Multi-Stakeholder-Gender-Empowering-Approach (PMMGA) and the Know-Plan-Practice-Learn-Act (KPPLA) cycle due to financial and time limitations, hence the need for further studies on implementation of the proposed systematic approach for enhancing protective workplace practices in ASGM.

2.7.2 Conclusion and Recommendations

This work confirmed numerous hazards amidst lacking adequate controls and compromised PPE use. Mercury pollution, accidents, injuries, HIV, TB, mosquitoes, and alcohol and drug use were identified. Underground excavations, overworking, violence and ASM mechanisation were among the high-risk workplace factors. Informal practices were inherent. Gendered health and safety issues affecting children and women included child labour and unequal access. The disabling contributing causal factors of compromised protective workplace practises were multiple. Successive layers were proposed to enhance protective workplace practices. However, each successive layer was characterised by gaps and limitations. The Progressive Multi-Stakeholder-Miner-Centric-Gender-Empowering-Approach (PMMGA) was suggested together with the Know-Plan-Practice-Learn-Act (KPPLA) cycle. Application of the KPPLA cycle could also be enabled by comprehensive formalisation. The business approach was suggested since ASGM in Zimbabwe is fundamental to national economic strategy and is also practised by ASM companies. This study recommends prioritisation of comprehensive formalisation for policymakers. Furthermore, influential actors in ASGM could integrate protective health and safety practices in ASGM activities. Academic institutions could also support further operational research on the enhancement of protective workplace practices in ASGM.

2.7.3 Contributions to New Knowledge and Significance of Study

- This study has
  - provided a current assessment of hazards; controls; health and safety events; and gendered health and safety factors in artisanal-small-scale gold mining.
  - applied concepts such as risk assessment, the Swiss cheese model, the hierarchy of controls, the Plan-Do-Study-Act cycle, and the enhancement of protective workplace practices to artisanal-small-scale gold mining.
  - created new knowledge on multi-causal analysis of disabling causal factors, successive protective layers, the Know-Plan-Practice-Learn-Act (KPPLA) cycle, and the Progressive-Miner-Centric-Multi-Stakeholder-Gender-Empowering-Approach (PMMGA).
  - provided an integrated model for enhancing protective workplace practices in artisanal-small-scale gold mining.
- The study topic is significant and relevant to artisanal-small-scale gold mining as well as local and international initiatives including policy making; the planet gold; responsible mineral sourcing; and sustainable development goals (SDGs) on: decent work and economic growth (SDG8), gender equality (SDG 5), good health and well-being (SDG 3), clean water and sanitation (SDG6), no poverty (SDG1), zero hunger (SDG2), affordable and clean energy (SDG 7) and climate action (SDG 13).

2.7.4. Implications for Future Research

This study points to the need for more work on:

⇒ Enabling and motivating factors for enhancing protective workplace practices in artisanal-small-scale gold mining.

⇒ Economic gains associated with the enhancement of protective workplace practices in artisanal-small-scale gold mining.

⇒ Observational and comparative interventions involving follow-ups and measurement of dust, noise, and underground fumes/oxygen levels in artisanal-small-scale gold mining.

⇒ Medical observations for health events (TB, HIV) in artisanal-small-scale gold mining.

⇒ Operation research and demonstration sites assessing the impacts of incorporating protective workplace practices in artisanal-small-scale gold mining.

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4. Publications

Annals of Global Health

Hazards and Control Measures among Artisanal and Small-Scale Gold Miners in Zimbabwe

ORIGINAL RESEARCH

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ABSTRACT

Background: In 2017 around 14–19 million miners were exposed to multiple hazards in artisanal and small-scale gold mining (ASGM). ASGM is characterized by basic and compromised mining methods with either very limited control of hazards or none at all. There is little knowledge about health and safety among artisanal and small-scale gold miners in Zimbabwe.

Objective: This study explores the interaction between hazards, control measures, and health and safety in Zimbabwe's ASGM.

Methods: Triangulation and mixed methods were applied using standardized questionnaires, Hazard Identification and Risk Assessment (HIRA), focus group discussions (FGDs), and summary notes from in-depth interviews (IDIs). Data were analyzed using descriptive statistics, regression analysis, and thematic analysis.

Findings: Quantitative data were collected through HIRA, which was conducted on 34 mining sites. 401 participants, selected through multi-stage sampling, were assessed through standardized questionnaires. Qualitative data was collected through six FGDs, and existing summary notes from 84 IDIs. The most prioritized hazards from the questionnaires were silica dust, noise, and workplace violence as indicated by 238 (62.0%), 107 (26.8%), and 104 (26.7%) respondents (respectively). HIRA identified noise, dust, unsafe shafts, violence, poor sanitation, and poor hygiene as key hazards requiring urgent attention. A key finding of this study was the poor application of the hierarchy of controls in managing workplace hazards. After adjusting for confounders, association with experiencing health and safety challenges was working underground (AOR = 2.0, $p = 0.03$), workplace violence (AOR = 3.3, $p = 0.002$), and long working hours (AOR = 2.8, $p = 0.019$). Injuries and fatalities were common without mitigation strategies.

Conclusions: ASGM in Zimbabwe is characterized by underground mining, long working hours, and workplace violence. The poor application of the hierarchy of controls is characterized by increased workplace injuries and fatalities. We recommend following the hierarchy of control measures in ASGM: elimination, substitution, engineering, administrative, and personal protective equipment.

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INTRODUCTION

Artisanal and small-scale gold mining (ASGM) involves gold mining through basic rudimentary and semi-mechanized methods [1]. ASGM is usually associated with poor health and safety standards [1]. In 2017, an estimated 14–19 million miners were employed in ASGM globally [2]. In Zimbabwe, over 500,000 people are involved in artisanal and small-scale mining, which is largely ASGM [3]. ASGM contributes directly to the sustenance of at least one million in Zimbabwe [4]. Mining regulations are the same for ASGM and large mines in Zimbabwe [5], and there are plans to formalize ASGM [6].

Mining is a high-risk sector requiring effective control measures to protect workers' health [5, 7, 8]. Occupational health and safety aims to prevent, manage, and control occupational hazards [9]. The hierarchy of control measures, from the most to the least effective, includes elimination, substitution, engineering, administrative, and personal protective equipment (PPE) [10]. Elimination and substitution are more feasible at the design and development stages and more challenging for existing operations [10]. Engineering control measures are designed to address hazards at the source [11] and are effective and less independent of human behavior, despite the cost [10]. PPE is less effective, owing to dependence on human effort [10, 11]. Mitigation control measures involves interventions to prevent and manage health and safety incidences [11]. The Swiss cheese model assumes successive layers of control measures marked by "eyes," of different shapes and sizes, which represent multiple weaknesses in those control measures and which are associated with accident opportunities [12]. This study assumes that the Swiss cheese model could be applicable to ASGM, which is associated with hazardous working conditions [1, 8, 13] and compromised control measures. ***Figure 1*** illustrates the interaction between hazards, PPE use, and health, safety, and environmental effects in ASGM.

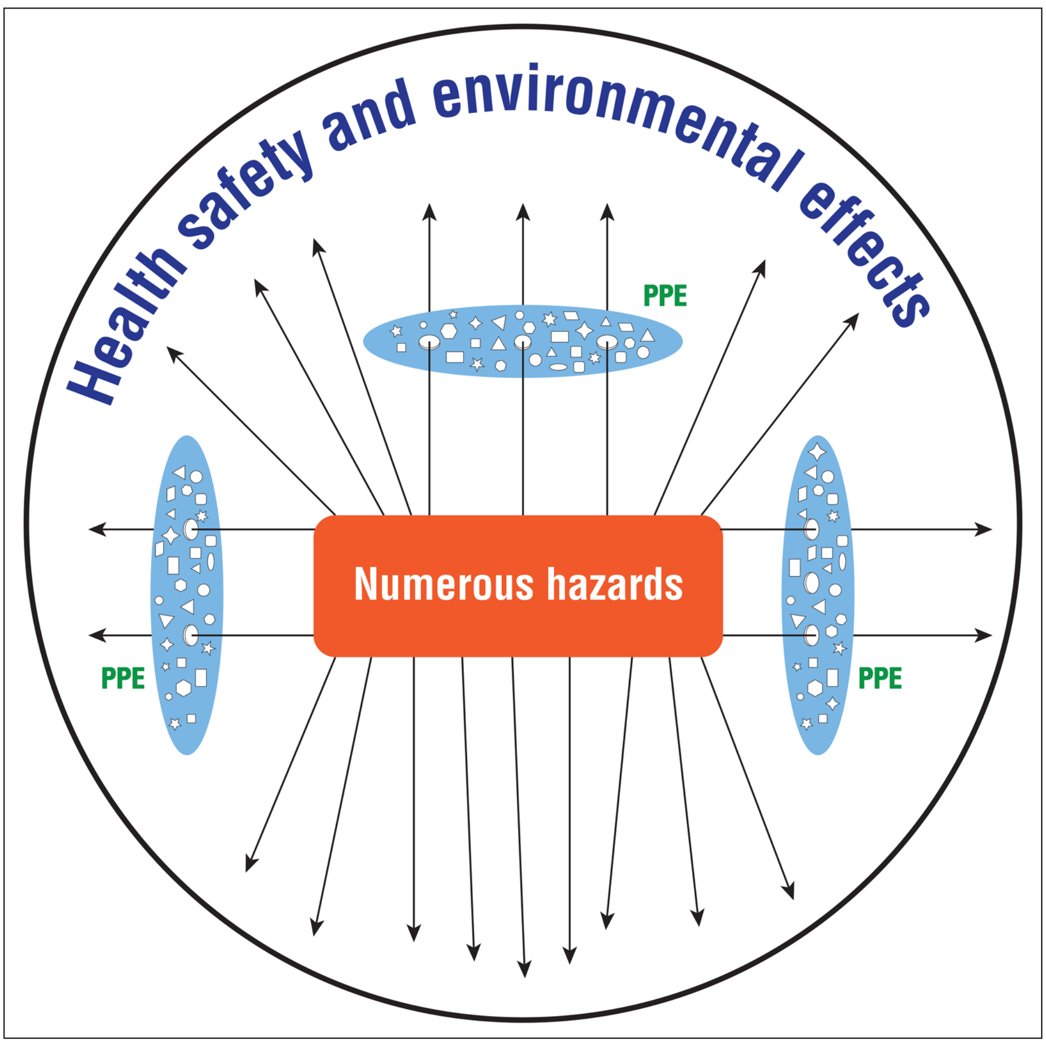

Figure 1 Numerous hazards and compromised control measures in ASGM: Interaction between hazards, PPE use and health, safety and environmental effects in ASGM in Zimbabwe.

The figure assumes that PPE is the most common control measure in ASGM in Zimbabwe. While the Swiss cheese model displays various successive layers of control measures [12], ***Figure 1*** assumes one layer of PPE characterized by various weaknesses and missing layers of control measures, resulting in increased adverse health safety and environmental effects in ASGM.

Global studies on ASGM found hazardous working conditions including dust, chemicals, and noise, as well as ergonomic, psycho-social, environmental, and biological hazards [14–16]. Studies on ASGM in Kadoma noted unsafe mining pits, lack of PPE use, lack of safe drinking water and toilets, low hygiene, and poor waste management [16, 17]. These conditions were associated with accidents, acute respiratory infections, tuberculosis, malaria, and sexually transmitted infections [16, 17]. It was also found that ASG miners have limited to near-absent access to health care [16, 17]. A cross-sectional survey among ASG miners in Midlands and Matabeleland South Provinces in Zimbabwe reported a high prevalence of silicosis (11.2%), tuberculosis (TB) (4.0%), and HIV (23.5%) [18]. A review on occupational health and safety (OHS) in Southern Africa revealed that OHS is grossly inadequate in the informal sector [19], which was confirmed by a global review on OHS in ASGM that found no studies on comprehensive occupational health interventions in ASGM [20]. ASGM informally employs more workers than large mines in many countries [8], without basic safety standards [8].

This study explores the interaction between hazards and control measures in ASGM in Zimbabwe. The objectives of this study are:

1) identifying hazards and controls in ASGM in Zimbabwe,
2) exploring the interaction between hazards and control measures, and
3) assessing the associated health safety and environmental effects.

METHODS

The study was conducted from November to December 2020 in Shurugwi and Kadoma, Midlands and Mashonaland West provinces of Zimbabwe that are characterized by high ASGM activities [21]. Triangulation, which involved integration of different methods to tackle the research phenomenon from different angles and the mixed method design that complements quantitative and qualitative methods on the same research problem were used for a comprehensive study. Data were collected using standardized questionnaires [22], Hazard Identification and Risk Assessment (HIRA), focus group discussions (FGDs), and summary notes from qualitative interviews taken from another survey that was conducted on ASGM in Kadoma in 2017 [17]. HIRA, standardized questionnaires, and focus group discussions were conducted in 2020 to both quantify and understand hazards, controls, and experienced health and safety effects [22]. All data collection tools were available in Shona and Ndebele. Data collection tools were pre-tested among eight miners from two mining sites in Kadoma and Gwanda in Zimbabwe. The tools were modified and translated into Ndebele and Shona by experienced translators and approved, together with the study protocol, by the Medical Research Council of Zimbabwe. All participants gave written informed consent to participate in the study.

QUANTITATIVE METHODS

QUESTIONNAIRES

Miners were interviewed using standardized questionnaires. The target population was ASG miners working in Kadoma and Shurugwi. The study sample was selected by multi-stage sampling. Firstly, active mining areas involved in rudimentary and more mechanized mining methods were selected purposively in Kadoma and Shurugwi. Secondly, stratified simple random sampling was conducted through reshuffling names of identified active sites practicing rudimentary and more mechanized mining methods. Lastly, participants in the selected sites were randomly selected by means of tossing a coin (considering proportional gender inclusion).

The questionnaires (Appendix 1), which was administered by the interviewer, focused on health and safety issues and was designed based on previous ASGM surveys in Kenya and Zimbabwe [17, 23]. Consenting adults aged eighteen years and above who had been involved in ASGM for at least six months were included. Drunk, disinterested, and non-cooperative respondents were excluded. Sites which were practicing rudimentary and more mechanized mining were visited in eight mining areas in Kadoma and Shurugwi.

HAZARD IDENTIFICATION AND RISK ASSESSMENT (HIRA)

The modified, standardized, and tested University of Cape Town baseline HIRA tool (Appendix 2) [24], with a risk matrix of 1 to 5; likely, minor, moderate, high, very high (Appendix 3) [25]. The assessment was conducted by a team trained through presentations that involved was used active participation. Training was conducted by the principal investigator experienced in risk assessment, with input from ASGM association leader experienced in training and researches in ASGM. The HIRA tool was fully developed and tested by other researchers (Appendix 3). Probability was weighted against the severity of impacts and frequency. The weighted risk (%) was calculated using the formula [24]:

$$Risk = \frac{\left[Probability \times Severity\left(I + P + E + C\right) \times Frequency\right] \times 100}{500}$$

Key (for the formula)
I Injury/disease
P Production
E Environment
C Cost

HIRA was conducted by the research team through direct observation, walk-through surveys, and informal discussions with workers on thirty-four sites in eight mining areas in Kadoma and Shurugwi. The final risk assessment score was moderated with input from experienced miners and ASGM Association leader who had more than thirty years in ASGM, was verified and reviewed by mining engineer from the Ministry of Mines and Mining Development, and independent ASGM experts, experienced in mining safety and ASGM in Zimbabwe. Risk scores were profiled for priority of action as shown below.

A	75%–100%	immediate attention needed
B	60%–74%	attention required in 1 week
C	45%–59%	attention required in 1 month
D	30%–44%	attention needed in 6 months
E	15%–29%	attention required in 12 months
F	1%–14%	attention required as soon as possible [24]

Risk profiling determined the urgency of response measures.

QUALITATIVE METHODS

FOCUS GROUP DISCUSSIONS (FGDS)

FGD participants who were miners for at least six months were selected by a local association leader experienced in ASGM through snowballing, which was guided by references from initial known contacts from different mining sites. A FGD guide (Appendix 4) was used to explore the following themes: hazards, existing controls, challenges on health and safety, and associated effects. The focus group discussions were conducted in Shona and were transcribed into MS Word in Shona before they were translated and transcribed into MS Word in English by experienced translators (and then verified by them). Three FGDs were conducted in the dry season in 2017 in Kadoma during a different survey [17], while three FGDs were conducted in the rainy season in Shurugwi in 2020. Data from different seasons were used to understand occurrences of hazards in different seasons.

EXISTING SUMMARY NOTES FROM IN-DEPTH INTERVIEWS

Summary notes from qualitative interviews taken in an earlier survey [17] that was conducted by University Hospital, LMU Munich, in October 2017 were used for the study. Snowball sampling was used through initial contact with potential participants. Nine mining sites were visited during the 2017 survey [17]. The in-depth interviews were conducted by a University Hospital, LMU Munich, research team. Themes for IDI included experiences with hazards and risks and PPE use (Appendix 5). The in-depth interviews were conducted in Shona, summarized, and translated into English.

DATA ANALYSIS

Data from the questionnaires and HIRA tool were entered, cleaned, and analyzed in SPSS version 20 (IBM SPSS, Chicago, Illinois, USA). HIRA risk scores were weighted, calculated into percentages, and categorized from A to F [24]. For risk assessment, the mode, median, and quartiles were calculated. Categorical data from the questionnaires were summarized using frequencies and percentages. The association between experiencing health and safety challenges and predictor variables such as age, gender, district, working hours, and violence was assessed using binary logistic regression and was presented as odds ratios (ORs) and adjusted odds ratios (AORs). The level of significance was set at $p = <0.05$. Qualitative data from FGDs and IDIs were analyzed using thematic analysis to explore the various hazards experienced by the miners, experienced health and safety effects, and experiences with accessing health services. Quotations from FGDs and notes from in-depth interviews were used to explain the findings from the questionnaires. As the standard questionnaires and HIRA had comprehensive results sufficient for this paper, coding and further analyses of data from FGDs and IDIs were not conducted for this paper.

ETHICAL APPROVAL

The study was approved by the University of Munich Ethics Committee (Project 20-068) and the Medical Research Council of Zimbabwe (MRCZ/A/2603). Consent was sought from local authorities, mine owners, and all participants. There was voluntary participation and signing of informed consent prior to data collection. Questionnaires were numbered without names to ensure confidentiality. The survey conducted in Kadoma in 2017 in the dry season was approved by MRCZ (MRCZ/B/1425) [17] and the University of Munich Ethics Committee (17-665) [17].

RESULTS

Quantitative data from the questionnaires had 401 respondents, with a response rate of 88%. Thirty-four site assessments were carried out during the study. Six FGDs were conducted. Summary notes from a different study with 84 respondents (15 women and 69 men) were also used [17].

SOCIO-DEMOGRAPHIC CHARACTERISTICS OF THE QUESTIONNAIRES STUDY POPULATION

The total sample consisted of 220 respondents from Kadoma and 181 from Shurugwi. The study population consisted of 69 women and 332 men. Fifty-one percent of the study population was married. Two hundred and twenty respondents were within the 18–35 age category as indicated in ***Table 1***.

CHARACTERISTICS		N (%)	TOTAL
Population per district		401 (100)	401
District n (%)	Kadoma	220 (54.9)	
	Shurugwi	181 (45.1)	401
Mine category (n (%)	Rudimentary	78 (19.5)	
	More mechanized	323 (80.5)	401
Gender n (%)	Female	69 (17.2)	
	Male	332 (82.8)	401
Marital status n (%)	Single	126 (31.9)	
	Married	202 (51.1)	
	Separated	17 (4.3)	
	Divorced	28 (7.1)	
	Widowed	22 (5.6)	395
Age (n (%)	18–35 years	212 (56.1)	
	36–50 years	130 (34.4)	
	Above 50 years	36 (9.5)	378
Education level n (%)	No formal school	28 (7.1)	
	Primary	59 (14.9)	
	Secondary	241 (60.9)	
	Tertiary	39 (9.8)	
	Vocational	29 (7.3)	396
Monthly Earnings n (%)	No Earnings	7 (1.9)	
	Less than 100 US$	212 (56.7)	
	Above 100–500 US$	13 (34.8)	
	Above 500–1 000 US$	24 (6.4)	
	Above 1000 US$	1 (0.3)	374
Roles n (% of cases)	Digging	211 (65.3)	
	Moving ore manually	59 (18.3)	
	Blasting	51 (15.8)	
	Loading	44 (13.6)	
	Washing/panning	33 (10)	
	Cooking	26 (7.9)	
	Amalgam burning	24 (7.3)	
	Milling	24 (7.3)	
	Sponsoring	22 (6.8)	
	Supervision	22 (6.8)	
	Mine owner	19 (5.9)	
	Gold buying	14 (4.3)	549 **(Total cases)**
Daily working hours n (%)	1–8 hours	259 (66.9)	
	Above 8–16 hours	82 (21.2)	
	Above 16–24 hours	46 (11.9)	387
Working underground n (%)	Working underground yes	201(52.3)	385
Working arrangements n (%)	Shares	229 (61.2)	
	Salary	89 (23.8)	
	Contract	35 (9.4)	
	Individual	21 (5.6)	374

Table 1 Socio-demographics: Socio-Demographic Characteristics of the Miners from Kadoma and Shurugwi in Zimbabwe in 2020 (n = 401).

Twelve percent of the participants worked for 17 to 24 hours daily, and 52% worked underground. More than 50% of the participants earned less than 100 United States Dollars (US$) per month. In addition, FGDs revealed challenges with unreliability of earnings, as one miner expressed,

> *'The challenge here is that people do not get money on time. The gold doesn't always come. You can work for 2–3 months without getting money while working. You can be affected working like this when nothing is coming out. We need to get money to live well.'*
> – Male miner, FGD[1]

PRIORITY HAZARDS PERCEIVED BY MINERS

The most prioritized hazard was silica dust, as indicated by 238 (62%) of the respondents, while noise and workplace violence were indicated by 107 (26.8%) and 104 (26.7%) respondents, respectively. Workplace violence was associated with loss of ore, gold, and equipment (n = 48, 53.9%) and loss of shafts (n = 16, 18%), as was confirmed by qualitative data (***Table 5***). Noise was common on sites that had equipment. For instance, one site had excess noise from six stamp mills that were operating simultaneously. The workers at that site had helmets, work suits, and foot protection, but they had no ear protection and no gloves. The noise levels were too high for ear protection alone. As a result, hearing problems were also reported as presented further.

REPORTED STANDARD OPERATING PROCEDURES (SOPS) AND PERSONAL PROTECTIVE EQUIPMENT (PPE) USE

Ninety-two respondents (25.6%) reported that they had SOPs, while 231 (59.8%) reported use of PPE, as shown below in ***Table 2***.

Table 2 Standard operating procedures (SOPs) and personal protective equipment (PPE) use: SOPs and PPE use reported by miners in Kadoma and Shurugwi, Zimbabwe, in 2020.

STANDARD OPERATING PROCEDURES AND PPE USE		N (%)	TOTAL
Standard Operating Procedures n (%)		92 (25.6)	360
Use of PPE n (%)		231 (59.8)	386
Replacement of PPE n (%)	Frequently	37 (34.9)	
	Rarely	49 (46.2)	
	Never	20 (18.9)	295
Means of getting PPE n (%)	Provided at work	104 (46.4)	
	Bought for self	104 (46.4)	
	Co-worker	13 (5.8)	
	Friend or family	11 (4.9)	
	Not Provided	68 (29.7)	106
Reasons for non-PPE use n (% of cases)	I don't know	68 (29.7)	
	Lack of awareness	39 (17)	
	Not affordable	35 (15.3)	
	Not comfortable	13 (5.7)	
	Not necessary	11 (4.8)	233 **(Total cases)**

Six percent of the participants were mine owners (***Table 1***). PPE was mainly provided at work or self-sourced. In Shurugwi, it was common for miners to source their own PPE. In Kadoma, some mine owners and sponsors were providing PPE to complement the PPEs sourced by individual miners. However, observed PPE use was lower than reported (***Tables 4*** and ***5***). Replenishing worn-out PPE was a challenge for more than fifty percent of the respondents. Thirteen of the respondents indicated that non-compliance to PPE use was due to discomfort associated with PPE use, which could stem from negative perceptions. The migratory nature of ASGM also posed an obstacle to

1 Data Set [3].

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PPE use (***Table 5***). Furthermore, the use of PPE alone was not sufficiently protective against mine collapses and heavy rock falls. As one respondent stated,

> *"Where they work is unsafe. They have PPE. They use it. PPE cannot stop mine collapses. Gumboots cannot prevent a heavy stone. PPE cannot protect a person against a heavy rock fall."* -Female miner, FGD[2]

The association between experiencing health and safety challenges and exposure to hazards is shown in ***Table 3***.

CHARACTERISTIC	TOTAL	HEALTH & SAFETY CHALLENGES		OR (95% CI)	AOR (95% CI)	
		NUMBER	(%)†			P VALUE
Overall	393	178	(45)			
Gender (n = 393)						
Male	326	148	(45)	1.0 (0.6–1.7)	0.5 (0.2–1.4)	0.1
Female	67	30	(45)	Reference	Reference	
Age (n = 370)						
>50	36	15	(42)	Reference	Reference	
36–50	128	59	(46)	1.7 (0.5–1.7)	1.1 (0.4–3.3)	0.9
18–35	206	90	(44)	1.3 (0.5–2.2)	1.3 (0.5–3.3)	0.7
District (n =393)						
Kadoma	215	94	(44)	Reference	Reference	
Shurugwi	178	84	(47)	1.2 (0.8–1.7)	1.1 (0.6–2)	0.7
Working underground n = (376)						
Yes	197	100	(51)	1.6 (1.1–2.4)**	2.0 (1.1–5.0)**	0.03**
No	179	70	(39)	Reference	Reference	
Moving up and down the shaft (n = 379)						
Yes	43	43	(100)	2.5 (2.5–3.3)**	–	0.1
No	336	122	36)	Reference	Reference	
Crushing (n = 379)						
Yes	22	22	(100)	2.5 (2.0–2.5)*	–	0.1
No	357	143	(40)	Reference	Reference	
Opening shaft (n = 379)						
Yes	21	21	(100)	2.5 (2–2.5)**	–	0.1
No	358	144	40)	Reference	Reference	
Workplace violence (n = 382)						
Yes	102	68	(67)	3.4 (2.1–5.5) **	3.3 (1.4–5.0)**	0.002**
No	280	103	(37)	Reference	Reference	
Working hours (n = 379)						
17–24	45	31	(69)	2.5 (1.1–5.0)**	2.8 (1.2–6.5)	0.019 **
9–16	80	38	(48)	3.3 (1.7–5.0)	1.4 (0.6–1.4)	0.4
1–8	254	106	(42)	Reference	Reference	

Table 3 Exposure to hazards and health and safety challenges: Association between experiencing health and safety issues and exposure to hazards reported by miners in Kadoma and Shurugwi, Zimbabwe, during the 2020 rainy season.

AOR = Adjusted Odds Ratio; CI = 2-sided confidence interval; † = row percentages; ** =statistically significant.

2 Data Set [3].

There were no significant differences in odds of experiencing health and safety challenges by gender, district, and age. After adjusting for other variables in the model, the odds of experiencing health and safety challenges were higher for miners who reported working underground, AOR= 2.0, [1.1–5.0], miners who had experienced workplace violence, AOR = 3.3 [CI = 1.4–5.0], and miners who had long daily working schedules of 17–24 hours, AOR = 2.8[1.2–6.5]. A case of three miners who were trapped underground around three o'clock in the morning in Zvishavane during the 2020 rainy season was mentioned. Such cases were reported as typical (***Table 5***).

One hundred and seventy-eight participants (45%) reported having experienced health and safety challenges (***Table 3***). The major health and safety problems experienced were respiratory (n = 33, 26.6%), musculoskeletal (n = 29, 23.4%), stress (n = 28, 22.6%), and injuries (n = 24, 19.4%). Hearing (n = 10, 8.1%), and reproductive problems (n = 4, 3.2%) were also reported. Experienced health and safety problems could be linked to exposure to dust, heavy lifting, and unsafe shafts (illustrated in ***Table 3***). FGDs revealed that stress was related to sicknesses among ASG miners (***Table 5***). Stress was also resulting from low and erratic wages, as presented above. The common reported injuries were fractures (n = 34, 52.2%), cuts (n = 24, 41.4%), and bruises (n = 22, 37.9%). The reported ever-injured body parts were hand(s) (n = 38, 28.1%), leg(s) (n = 32, 23.7%), finger(s) (n = 24, 17.8%), head (n = 19, 14.1%) and chest (n = 15, 11.1%). One miner, in FGD, explained that loss of fingers was common at the milling centers (***Table 5***). Protection of miners at milling centers was compromised as explained above.

Access to health care was limited. Consequently, there was a tendency of seeking health care from alternative options other than mainstream care. Alternative health-seeking options included prophet/prayers (n = 26, 57.8%), pharmacy (n = 9, 20%), traditional healers/ herbalist (n = 3, 6.7%), self-medication (n = 2, 4.4%) and illegal drug dealers (n = 2, 4.4%). Miners resorted to alternative health-seeking options because they could not afford hospital costs, as further revealed in ***Table 5***.

IDENTIFIED HAZARDS AND RISKS (HIRA)

The identified hazards and risk scores are illustrated below.

	SITES (N)	SITES IN CATEGORY A 75–100% N (%)	MODE	MEDIAN	QUARTILES 25TH	50TH	75TH
Environmental and physical hazards							
Noise	23	10(43)	34(D)	55(C)	34(D)	55(C)	80(A)
Uncovered old mining pits	21	5(24)	40(D)	58(C)	42(D)	58(C)	75(A)
Stagnant water	8	1(13)	22(E)	27(E)	22(E)	27(E)	52(C)
Lack of toilets	24	8(33)	100(A)	37(D)	30(D)	37(D)	79(A)
Mine contaminated drinking water	7	4(57)	I00(A)	100(A)	22(E)	100(A)	100(A)
Indecent shelter	7	1(14)	5(F)	47(C)	22(E)	47(C)	61(B)
Water pools in panning sites	1	1(100)	100(A)	100(A)	100(A)	100(A)	100(A)
Mining activities around homesteads	15	6(40)	100(A)	64(B)	30(D)	64(B)	81(A)
Electricity	6	6(100)	100(A)	98(A)	84(A)	98(A)	100(A)
Clutter	8	3(36)	100(A)	46(C)	25(E)	46(C)	94(A)
Lack of fencing/signage	24	9(38)	100(A)	61(B)	30(D)	83(A)	100(A)
Lack of PPE	25	12(48)	100(A)	70(B)	37(D)	70 (B)	94(A)

(Contd.)

	SITES (N)	SITES IN CATEGORY A 75–100% N (%)	MODE	MEDIAN	QUARTILES 25TH	50TH	75TH
Mechanical hazards							
Unsafe shaft support	18	9(50)	100(A)	83(A)	51(C)	83(A)	100(A)
Equipment	19	8(42)	68(B)	68(B)	52(C)	68 (B)	90(A)
Chemical hazards							
Chemicals	25	17(68)	100(A)	100(A)	66(B)	100(A)	100(A)
Contamination of food	6	1(17)	32(D)	32(D)	24(E)	32(D)	72(B)
Mine contaminated drinking water	7	4(57)	I00(A)	100(A)	22(E)	100(A)	100(A)
Chemical contamination of farmland	7	4(57)	32(D)	80(A)	32(D)	80(A)	100(A)
Mine waste	20	4(20)	22(E)	43(D)	35(D)	43(D)	68(B)
Silica dust	29	16(55)	65(B)	75(A)	65(B)	75(A)	86(A)
Ergonomic hazard(s)							
Confined working space	21	3(14)	24(E)	32(D)	22(E)	32(D)	72(B)
Manual Lifting	21	7(33)	54(C)	62(B)	38(D)	62(B)	77(A)
Psycho-social hazards							
Conflicts & violence	5	1(20)	32(D)	40(D)	34(D)	40(D)	68(B)
Child labor	21	5(24)	100(A)	48(C)	35(D)	48(C)	75(A)
Alcohol abuse & smoking	11	7(64)	100(A)	100(A)	24(E)	100(A)	100(A)
Prostitution	6	4(67)	100(A)	90(A)	71(B)	90(A)	100(A)
Security hazards							
Lack of security guards on-site	4	1(25)	22(E)	58(C)	29(E)	58(C)	78(A)
Biological hazards							
Crocodiles & snake bites (gold panning)	5	–	22(E)	43(D)	29(E)	43(D)	55 (C)

Table 4 Hazards and risks in ASGM: Identified hazards and weighted risk scores (%) from mining sites in Kadoma and Shurugwi, Zimbabwe, during the 2020 rainy season (n = 34).

The majority of the identified hazards required immediate attention. Silica dust and noise required immediate action on 16 (55%) and 10 (43%) individual sites, respectively. Observed sources of silica dust were dumps, dry blasting, lashing, and dry crushing. Engineering controls such as water sprays for blasting, crushing, and milling (hammer mills) were lacking on visited sites. Furthermore, risk assessment was conducted during the rainy season, when the majority of the miners had no protection against dust—unlike during the dry season in 2017, when more miners had cloths, such as mutton cloths, for protection against high levels of dust. PPE use had challenges as confirmed in ***Tables 2*** and ***5***. Occupational alcohol abuse and smoking were also reported in ***Table 5***. Unsafe shaft support was associated with fatalities (***Table 5***). ***Table 4*** shows uncovered mining pits, and stagnant water which is associated with mosquitoes and malaria. Miners also reported injuries, respiratory problems, and musculoskeletal problems, which could be linked to exposure to unsafe shafts, dust, and heavy lifting in ***Table 4***, as mentioned above.

ENVIRONMENTAL HAZARDS

The Gadza River in Shurugwi was dry in the rainy season. River siltation could be associated with water scarcity for agriculture and consumption. Some farmers in Shurugwi were also transitioning to ASGM on farming land due to persistent droughts. In Kadoma, some farmers discovered gold within their homesteads and started mining which was associated with chemical (mercury and cyanide) contamination of drinking water and farmland. However, mercury pollution is not further pursued in this study (***Tables 4*** and ***5***). There were no signs of reforestation, rehabilitation, or climate change awareness.

REPORTED EXPERIENCES OF MINERS: FOCUS GROUP DISCUSSIONS (FGDS) AND IN-DEPTH INTERVIEWS (IDIS)

As reflected below, numerous hazards in ASGM were confirmed in FGDs and IDI.

THEMES	EXAMPLES OF QUOTES FROM IN-DEPTH INTERVIEWS (IDIS) AND FOCUS GROUP DISCUSSIONS (FGDS)
Physical hazards	*"Mining of pillars"* – Male miner, 31 years old, IDI *"noise from blasting and drilling from jackhammer without earmuffs"* – Male miner, 70 years old, IDI
	"Heat and limited working space underground" – Male miner, 48 years old, IDI
	"Most of the shafts have poor ventilation below the expected standards" – Male mine owner, FGD
	"Shaking during blasting causes cracks, falling rocks and collapsing mines" – Male miner, 25 years old, IDI
	"Rock falls, collapsing mines, breaking ropes. People can get injured or die" – Male miner, 48 years old, IDI
	"Incidences of mining in small holes where people get closed in, in the rain season, and most of such cases in informal mining are realized later" – Male miner, 70 years old, IDI
Chemical hazards	*"… dust especially from using the jackhammer"* – Miner, FGD *"Water for washing and drinking. In old shafts, the water can be contaminated with chemicals and acids from blasting fumes and acids"* – Miner, FGD
	"The issue is thirst has no timetable. One can get thirsty at any time, especially when one is working. So when you are working and dehydrated, you do not think of health issues; you think of quenching the thirst and going back to work. So when we see clear water and do not get immediate effects after drinking, we assume all is well. So when working underground, we drink the mine water underground" -Miner, FGD
Lack of PPE	*"Respirators are needed because those fumes from blasting can cause problems like TB. When the fumes are still there, there is a need to wear respirators. Respirators are needed; they must not run out. We are not using respirators because of a lack"* – Miner, FGD *"PPE wears out before one gets money for a replacement, and it is difficult to buy for oneself"* – Male miner, 26 years old, IDI *"We operate on share ownership. I have the capital to sponsor the mine, but both the mine owner and the miner must buy PPE. The challenge is if the mine owner provides PPE, the new miner can disappear in 2 hours, and you buy again for the next employee"* – Mine owner, FGD
Biological hazards	*"There is something … faced in mines, insects such as mosquitoes get in the mines and bite people. Then rodents and rats come with ticks. There are other places named Ticks where ticks are in an area with gold, and people get attacked and injured by ticks"* – Mine owner, FGD *"Another point I had forgotten, people get bitten by snakes, snakes hide in timbering. Yes, yes, yes, we have had serious cases where people get bitten by snakes and die. There is also the problem of scorpion bites"* – Mine owner, FGD
Psycho-social hazards	*"Taking drugs like marijuana is common in ASM."* – FGD with miners' wives *"you get sick because of stress"* – Miner, FGD *"There is also the challenge with 'Member' (machete gangs) who raid and attack miners"* – Mine owner, FGD
Themes	**Examples of effects of safety and health issues: losses and fatalities**
Injuries, loss of ores, loss of body parts, and loss of ability to work	*"There is also the challenge with …. many people raid and attack miners and get other people's ores. They can siege mine owners to injure and raid them. There are many cases like that"* – Mine owner, FGD *"Loss of ability to work"* – Male miner, 33 years old, IDI *"Common accidents at the mill involve loss of fingers when collecting the sands (milled ore) from the box"* – Male miner, 39 years old, IDI *"Injuries from a mine collapse in the rain season"* – Male miner, 33 years old, IDI One mill operator had an injured finger. He explained that he was fixing the hammer mill without gloves and was cut by loose parts of the hammer mill when he got injured. He acknowledged that the mine owner had provided gloves, but he was not using the gloves – Site observations
Fatalities	*"There was a guy who got into the shaft alone, was closed, and died"* – Male miner, 70 years old, IDI *"Shaking during blasting causes cracks, falling rocks, and collapsing mines, which can cause fatal injuries beyond rescue. Catastrophic injuries are common once in a while"* – Male miner, 29 years old, IDI *"Another point I had forgotten…, people get bitten by snakes, snakes hide in timbering. Yes, yes, yes, we have had serious cases where people get bitten by snakes and die. There is also the problem of scorpion bites"* – Mine owner, FGD

(Contd.)

THEMES	EXAMPLES OF QUOTES FROM IN-DEPTH INTERVIEWS (IDIS) AND FOCUS GROUP DISCUSSIONS (FGDS)
	"…many people die of mine accidents and collapsing mines" – Male miner, 70 years old, IDI *"Accidents and loss of life due to lack of skilled blasters"* – Male miner, 32 years old, IDI *"For now, we mine for 5–6 years, and we die. This causes artisanal miners to die. Artisanal miners are dying'* – Miner, FGD
Accessibility of health services	*"We do not go anywhere at all. We go only when we are in severe pain"* – FGD with miners *"The hospital requires money; you have to raise your own money to go to the hospital, including money for transport. When you do not have [money] you just take paracetamol and keep working"* – Miner, FGD *"People can die without seeking health care. Delayed health-seeking is caused by transport challenges to get to the referral hospital"* – Miner, FGD *"It [accessing health care services] depends on whether you are injured or not. If injured, a police report is required."* – Miner, FGD *".... if one gets approval to go to Kadoma General Hospital, there is no medicine at the hospital. We used to get medicine at the dispensary within the hospital, but now there is no medicine at Kadoma General Hospital. One has to go to town to get medicine from the pharmacy."* – Miner, FGD

Table 5 Hazards, health and safety effects; and accessibility of healthcare: Reported miners' experiences with hazards, health safety, environmental effects, and availability of health services from FGDs and IDIs conducted among miners in Kadoma and Shurugwi in the 2017 dry season, and the 2020 rainy season.

Qualitative data confirmed experiences of physical, chemical, biological, and psycho-social hazards. As shown in ***Table 5***, rock falls and mine collapses were reported as typical, especially in the rainy season. Sources of noise included blasting and drilling with jackhammers. Sanitation and hygiene were poor. There was no compliance to COVID-19 protocols on the majority of the visited sites. Reported effects included deaths, injuries, loss of ores, and loss of ability to work. The majority of the miners had no health coverage. Health seeking was delayed and denied due to lack of money and requirements to provide a police report in the event of accidents.

DISCUSSION

Findings revealed numerous hazards that required immediate attention; engineering controls and risk mitigation measures were missing, while PPE use was highly susceptible; to weaknesses and there was no prioritization of the hierarchy of controls. Almost 50% of survey participants had experienced health and safety challenges. Working underground, long working hours, and workplace violence were associated with experiencing health and safety issues at work. PPE was the common control measure; PPE was characterized by numerous weaknesses, which could result in increased adverse health, safety, and environmental issues. This section discusses the interaction between hazards and controls and the associated health and safety effects, with specific reference to PPE use, as well as missing engineering and risk mitigation controls.

Exposure to hazards with lacking and compromised PPE use demonstrated the vulnerability of PPE. While mine owners were required to provide PPE [5], the mine owners preferred individual miners (workers) to source their own PPE. Giving PPE to the miners was also challenged because of the migratory nature of ASGM, negative perceptions, and non-compliance, which is revealed in previous findings [25]. Simultaneously, the miners could not afford to buy PPE, ostensibly because of low earnings; this is supported by the literature [10, 14, 17]. Consequently, the replacement of PPE posed challenges in the sector. Smoking, alcohol abuse, and drug abuse were prevalent at work. This is interlinked with low compliance to PPE use [26]. It could be argued that PPE use was highly endangered with weaknesses of different shapes and sizes [12] (***Figure 1***) in the presence of numerous hazards. Compromised PPE use in ASGM could be associated with opening holes and weakening control measures [12], resulting in increasing odds of adverse health and safety effects [14].

Lack of effective control measures such as engineering controls undermines the safety and health of miners despite the prioritization of PPE [10]. Miners reported experiences of health and safety problems, including injuries, respiratory problems, and hearing problems, which have also been found in previous studies [14–18]. Wet crushing, noise-proof mechanisms, and securing standard shafts were lacking. Simultaneously, engineering control measures are associated with high costs [10], while ASGM is associated with low capital [1]. Hence engineering controls such as sinking standard safe shafts could be unaffordable for the majority of ASG miners in Zimbabwe because of low levels of capital. Concurrently, the odds of experiencing safety and health issues were two times higher when exposed to underground mining. In Zimbabwe, there has been a discussion among experts and stakeholders for regulations that address the needs and issues that are common in ASGM [27]. On the other hand, while the Environment Management Agency and Ministry of Mines and Mining Development have the mandate to offer training services to ASGM in Zimbabwe, ASGM has been growing fast, and there is limited capacity to train, implement, inspect, and monitor ASGM activities [28], thus increasing and opening more "holes" and "eyes" of various shapes and sizes in different positions in control measures [12]. Since ASGM is associated with limited capital, there is a need to address holes and weaknesses in the hierarchy of control measures by raising awareness and financing the prioritization of effective control measures.

Missing control measures threaten ASGM. In this work, defenses against hazards associated with sanitation and hygiene were compromised, as evidenced by lack of toilets, consumption of chemically contaminated water, and absence of hand washing facilities during COVID-19. Previous research has found sanitation and hygiene deficient in ASGM [15–17], which is associated with the spread of diarrheal diseases, tuberculosis, and malaria [14, 16–18, 29]. In addition, this study was conducted during the COVID-19 crisis, and the majority of the visited sites were not complying with defined COVID-19 protocols [30], pointing to missing control measures, in general. Health-seeking behavior was also low, partly due to lack of health coverage and the requirement to produce of an accident police report in order to access health services in the event of an accident. Access to health care services was limited [16, 17] thus pushing some miners to resort to prayers/prophets, illegal drug sellers, and self-medication. Poverty and inaccessibility of health care centers are associated with low uptake of health care services [16, 17].

Occurrences of fatalities in the absence of risk mitigation strategies exposed the miners. Mine collapses were common, especially in the rainy season. According to the McFarlane 2019 data set on ASGM fatalities, Zimbabwe experienced 42 ASGM fatalities in 2019 [31]. Working underground was associated with the double odds of experiencing safety and health issues. ASGM fatalities were therefore associated with negative outcomes for individual miners, their families, and ASGM communities in the absence of risk mitigation strategies. This is demonstrated by the case of a woman who lost her 34-year-old husband on December 8, 2020; the late husband was trapped underground while mining in the rainy season [32]. The widow had no compensation, no security cover or risk mitigation strategy. The majority of questionnaires respondents were married men, aged between 18 and 36 years, who were working underground. Underground fatalities entailed the loss of a young male workforce, which could contribute to adverse social, emotional, and moral impacts on families and ASGM communities [33]. The combined vulnerabilities due to exposure to numerous hazards without mitigation strategies could result in increased odds of experiencing health and safety issues and the intensification of adverse effects [34]. Hence, the relevance of risk mitigation strategies that address holes and weaknesses in control measures is clear, because they promote the health and safety of miners and ASGM families and communities [8, 33].

Environmental threats were found in this study, which complements existing literature [1, 13–15, 31]. Washing of alluvial ores in rivers could contribute to the siltation of the Gadza River, which could result in water scarcity [13–15]. Underground mining, which is common in Zimbabwe, is also associated with heavy water consumption and falling water-table [35]. Water scarcity due to ASGM activities could contribute to community conflicts [35, 39, 40]. There is evidence of conflicts between farmers and ASG miners in Zimbabwe [28]. While persistent droughts had pushed some communities in Shurugwi into ASGM, increasing impacts of climate change such as heat stress and water scarcity are potential threats to [35] ASGM. Destruction of the ecosystem is also associated with increased respiratory diseases [36]. Administrative control measures such as awareness-raising on reforestation, rehabilitation, and climate change or planetary health were lacking.

Some scholars have viewed ASGM as an inherently dangerous and unsustainable sector [37] because of hazardous working conditions with compromised control measures. On the other hand, artisanal and small-scale mining has significantly contributed to the world's mineral production, job creation [8, 31] and livelihood sustenance [4]. In Zimbabwe, where ASGM has a significant economic role, the government and the international development community have supported the sector [6]. In 2012, the United Nations Environmental Program (UNEP) set the global initiative to reduce and, where feasible, eliminate mercury use in gold processing in ASGM [38]. Simultaneously, the international market and consumer certification approaches have set specific standards, including legitimacy, elimination of child labor, universal human rights, non-illegal involvement of security forces, and responsible mercury use as the benchmark for accessing fair international markets for gold from ASGM [39, 40]. In Zimbabwe, there have been awareness-raising and routine inspections on PPE use in ASGM. However, as discussed above, there is no focus on comprehensive health and safety measures involving hazard identification and implementing adequate control measures. Hence the need to prioritize the hierarchy of control measures, which requires formalization of the sector in order to address health and safety issues in ASGM.

LIMITATIONS

Data from the questionnaires, in-depth interviews, and focus group discussions were self-reported; recall and response biases were possible in reporting. However, direct hazard identification was also conducted while triangulation and the mixed method complemented strengths of qualitative and quantitative methods.

Findings may also have limited generalizability beyond Kadoma, Shurugwi, and Zimbabwe. Simultaneously, the study districts typify ASGM activities across Zimbabwe. This corroborates relevant studies on health and safety in ASGM. Therefore, the study may contribute significantly to ongoing research in the health and safety discipline in ASGM, both nationally and globally.

CONCLUSION

Findings from this work confirmed numerous hazards inherent in ASGM in Zimbabwe and the need for these hazards to be addressed immediately. PPE was the common control measure, which was characterized by multiple weaknesses, while engineering controls and risk mitigation measures were missing. The interaction between numerous hazards, inadequate protection, and missing control measures was associated with adverse health, safety, and environmental effects. Numerous holes in PPE use and missing engineering controls and risk mitigation measures could be associated with at least a double increase of health, safety, and environmental effects when exposed to working underground, workplace violence, and long working hours. Therefore, it is imperative to prioritize the hierarchy of control measures in order to promote the health and safety of the workforce in ASGM.

RECOMMENDATIONS

Financing and prioritizing observation of the hierarchy of control measures is indispensable to promoting the health of workers in ASGM. These control measures include securing safe shafts; wet blasting, wet crushing, and wet milling; managing noise levels; improving sanitation and hygiene; raising awareness on climate change; and increasing accessibility to health care.

ADDITIONAL FILES

The additional files for this article can be found as follows:

- **Appendices.** Appendix 1–5. DOI: *https://doi.org/10.5334/aogh.3621.s1*
- **Data set.** 20202 Health and Safety Survey among Artisanal and Small-Scale Gold miners in Kadoma and Shurugwi, Zimbabwe. DOI: *https://doi.org/10.5334/aogh.3621.s2*

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

Data was accessible to all authors. All authors had a role in writing the manuscript.

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Accidents, Injuries, and Safety among Artisanal and Small-Scale Gold Miners in Zimbabwe

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Abstract: Artisanal and small-scale gold mining (ASGM) employs 14–19 million people globally. There is limited research on accidents, injuries, and safety in Zimbabwe's ASGM. This study investigates the prevalence of accidents and injuries, as well as the associated risks and existing safety practices. A cross-sectional survey was conducted among artisanal and small-scale gold miners. Data from 401 participants were analyzed using descriptive statistics and regression analysis. The prevalence of accidents and injuries was 35.0% and 25.7%. Accidents associated with experiencing injuries included mine collapses and underground trappings. The major injury risk factors were digging, blasting, being male, being 18–35 years old, crushing, and the underground transportation of workers and materials. Injuries were reported highest among the miners working 16 to 24 h per day. Participants had heard about personal protective equipment (PPE). There was training and routine inspections mainly on PPE use. Mine owners and supervisors were reported as responsible for OSH, which was mainly PPE use. Practices including the use of wire winch ropes and escape routes were rare. There was ignorance on underground mine shaft support. The mining regulations that had the potential to introduce comprehensive safety controls were not adaptable. We recommend applicable health and safety regulations for Zimbabwe's ASGM.

Keywords: accidents; injuries; risk factors; control measures; safety; artisanal and small-scale gold miners; Zimbabwe

1. Introduction

Recent global estimates assert that 14–19 million people are employed in artisanal and small-scale gold mining (ASGM) [1]. In Zimbabwe, ASGM is one of the informal sectors with a key economic role as it serves as a fundamental livelihood source [2]. This role has recently expanded as a result of persistent droughts and increasing unemployment rates worsened by the negative impacts of COVID-19.

Zimbabwe's unemployment rate in 2019 was estimated at 16% with 76% employed in the informal sector [3]. With more than 500,000 citizens working in artisanal and small-scale mining (ASM) [4] (mainly ASGM), ASGM is a significant source of informal employment in the country. ASGM varies in its formality and legality, operating through basic, manual, or primitive methods, and is usually associated with little or no attention to health and safety [5,6]. In 2019 alone, Zimbabwe had an estimated 4124 occupational injuries with a national occupational injury rate of 4.8 per 1000 and 6.7 per 1000 for large-scale mining (LSM) [3], which was based on claims made to the National Social Security Authority (NSSA). ASGM employs more people than large-scale mines, and the prevalence of global ASM occupational injuries is approximately seven times higher than in large mines [6].

ASGM is characterized by a high prevalence of injuries and fatalities due to numerous hazards and a lack of safety standards [6]. According to McFarlane's online media data set on ASM fatalities, 592 fatalities were reported globally in 2020, while 42 fatalities were recorded in Zimbabwe [7]. A study on occupational accidents in artisanal mining in the Democratic Republic of Congo (DRC) found the occurrence of accidents at 32.9% for the miners who were handling heavy loads [8]. Estimated injury rates in Ghana were 45.5 and 38.5 per 100 person-years in 2011 and 2013, respectively in a cohort study [9]. A study on injuries among ASGM miners in Ghana revealed experiences of catastrophic injuries due to collapsing underground mining pits [10]. Accidents in ASGM lead to injuries and fatalities of different intensities [10], including fractures, cuts, bruises, and loss of life [10–14]. Alcohol consumption, drug use, and smoking cigarettes at work are common in ASGM within Zimbabwe [11,12,15]. In Kenya, injuries in ASGM were associated with increased occupational alcohol and drug use [16].

Underground ASGM is widespread in Zimbabwe. Unfortunately, so are the risks associated with mine collapses and accidents [7,17]. Literature has revealed that underground mining is associated with processes requiring effective control measures [18,19]. Furthermore, underground artisanal and small-scale gold mining has been described as inherently hazardous [19,20]. Previous studies on ASGM in Zimbabwe have found compromised personal protective equipment (PPE) use, unsafe underground shafts, and low compliance with mining regulations [11,12,15]. Furthermore, a case-control study on severe occupational injuries at a mining company in Zimbabwe identified working underground, insufficient PPE use, and working shifts longer than eight hours as risk factors associated with severe injuries [14]. In Ghana, poorly supported underground shafts and poor pit designs resulted in ground failures, leading to fatalities and injuries of varying severity [10]. Studies have depicted digging, shaft sinking, underground mining, blasting, crushing, and long working hours as high-risk factors associated with accidents and injuries in Ghana's ASM sector [19,20]. Experts have therefore acknowledged the need for support systems for underground excavations, hence the relevance of technical backing in ASGM in Zimbabwe [18].

Accidents and injuries can result in multiple losses [21], e.g., lost income, time lost to injuries, and loss of production [22,23]. Contrarily, a healthy workplace is correlated to improved safety and increased mine production [22,24]. Risk management is therefore imperative in mining safety and health [22], and integral to a substantial decline in injuries in mining [22,25]. An effort is being made by the Ministry of Mines and Mining Development, non-governmental organisations (e.g., Pact), ASM associations, and mine owners to raise awareness and improve PPE use in Zimbabwe's ASGM sector. However, PPE use is the least effective control measure [26]. A single layer of PPE use alone is inadequate to mitigate mining risks [18,19,22,25] as illustrated in A and B of Figure 1: modified after Figure 1 in our previous article [12].

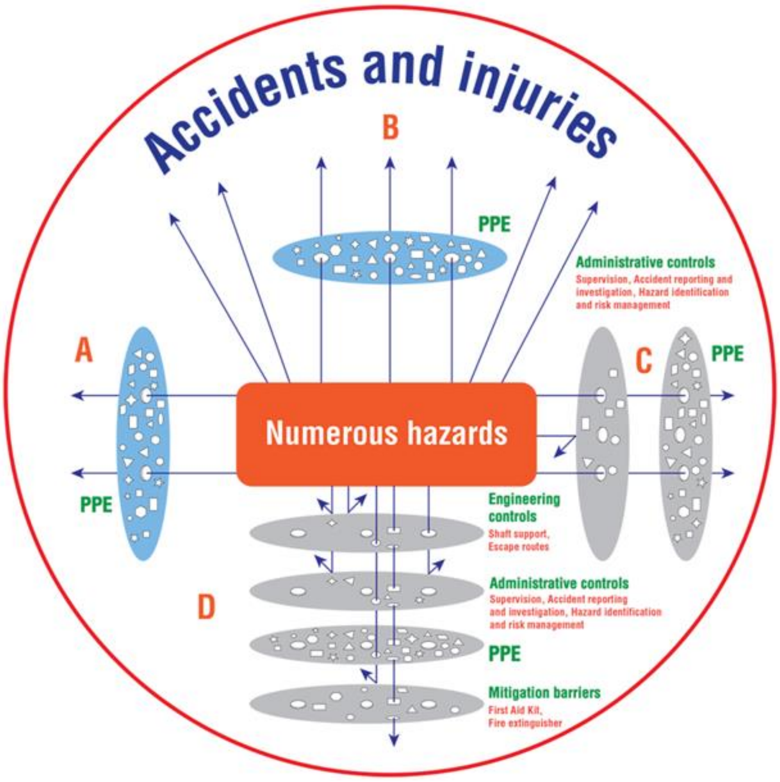

Figure 1. Numerous hazards and successive defensive layers: Risk management and accident prevention in ASGM in Zimbabwe modified after [12]. Key: High exposure to hazards: A and B; Single layer of control measures, e.g., PPE; Reduced exposure to hazards: C; Double layer of control measures, e.g., PPE, administrative controls; Comprehensive protection: D; Successive layers of control measures, e.g., engineering controls, administrative controls, PPE, and mitigation barriers.

The Swiss cheese model, which simplifies the correlation between exposure to hazards, vulnerable control measures, and the likelihood of the occurrence of accidents, assumes various layers of control measures characterized by "holes" of different shapes and sizes (Figure 1), representing multiple weaknesses in the control measures, resulting in accident opportunities [21]. The ranking of the hierarchy of controls from the least to the most effective is PPE, administrative controls, engineering controls, substitution, and elimination [26]. Elimination and substitution controls are challenging for existing operations [26]. Simultaneously, engineering controls are less dependent on human effort and are effective [26]. Fogler has applied the Swiss cheese model in engineering and has labeled the successive defense layers as engineering controls, administrative controls, behavioral controls, and mitigation barriers [27]. The Swiss cheese model has successfully been applied in the formal sector including large-scale mining (LSM) [28]. Successive layers of control measures could reduce accidents and injuries in ASGM [22,28]. However, ASGM is a poverty-driven, informal, and undercapitalised sector with a low degree of professionalism [5]. Research has indicated the lack of comprehensive occupational health and safety management in ASGM which is correlated to occurrences of accidents and injuries [19,29–31]. Smith, therefore, argues that ASM (which includes ASGM) should be prioritized as a high-risk sector requiring public health interventions including initiatives on occupational health and safety [30].

ASM in Zimbabwe is commonly unregulated, lacking technical and management skills [5], including safety and health management [32]. Effective control measures, such as standard mine shafts, are therefore missing and PPE is the common and compromised control measure [11,12,15]. There is high exposure to hazards for workers in ASGM [6,7], as shown in A and B of Figure 1. Reasons for reduced PPE use among workers in Zimbabwe's ASGM include unaffordability, non-compliance, and negative perceptions [11,12,15]. Missing and compromised control measures could result in multiple opportunities for accidents [21], as represented by the arrows in A and B in Figure 1. A double layer of control measures, C of Figure 1, could provide the opportunity to reduce exposure to hazards, e.g., through accident investigation that involves the management of identified causes of accidents [33,34]. Hazard identification and risk assessment is the initial step of risk control [31,32]. At the same time, training and supervision are fundamental elements of risk management [35]. Concurrently, administrative defenses (C of Figure 1) are rare in ASGM in Zimbabwe. Mining is defined as a high-risk sector in Zimbabwe [36], the mining regulations [36] therefore stipulate the required safety standards that incorporate successive defense layers [21] and an opportunity for comprehensive protection, as illustrated in D of Figure 1. However, mining regulatory standards are similar for both LSM and ASGM and there is limited capacity to comply with mining safety regulations in ASGM in Zimbabwe [37]. Scholars have found that mining regulations are ambiguous and deficient to address the dynamics of the ASGM sector in Zimbabwe [37,38]. Hence, the need for compatible mining regulations to address the needs of ASGM [37–39]. Although accidents and injuries are common in ASGM in Zimbabwe, there is limited research on injuries and accidents in ASGM in Zimbabwe. The aim of this study was to investigate the safety of miners involved in ASGM in Zimbabwe. Findings could be used to guide policies and relevant interventions to support the sector. The specific objectives of this study were to (1) assess the prevalence of accidents and injuries in ASGM, and (2) explore associated risk factors and safety management opportunities for ASGM in Zimbabwe.

2. Materials and Methods

The materials and methods in this section were published in our first article based on the same survey [12]. A cross-sectional survey was conducted through an administered questionnaire, (Appendix A) in the districts of Shurugwi and Kadoma from November to December 2020. Participants were selected by multi-stage sampling [12]. Mining areas that were actively involved in rudimentary and more mechanized mining methods were selected purposively in Kadoma and Shurugwi [12]. This was followed by a simple stratified random sampling by reshuffling names of identified sites that were involved in rudimentary and more mechanized mining methods [12]. Participants in the selected sites were chosen randomly while making sure to maintain proportional gender inclusion [12]. The target population was miners working in ASGM in Kadoma and Shurugwi [12]. Consenting adults, who were at least eighteen years old and with at least six months experience in ASGM, were included in the survey [12]. Miners who were intoxicated, who had low levels of literacy, were not comfortable filling the questionnaires with support, or were not interested in the study were excluded [12]. The purpose of the study was explained to the participants. Questions on the research were addressed and consent forms were signed before any participants completed the questionnaire.

2.1. Study Area

Shurugwi and Kadoma districts are in the Midlands and Mashonaland West provinces of Zimbabwe, respectively. The national survey on ASGM in Zimbabwe found that Midlands and Mashonaland West were the most active provinces in terms of ASGM mining activity density, the density of processing sites, and the number of formally registered gold milling sites.

ASGM activities in Kadoma and Shurugwi involve unlicensed groups and individuals, licensed individuals and groups, and licensed small-scale mining companies [40]. Rudimentary and more mechanized mining operations are common in Kadoma and Shurugwi. Sites practicing these types of mining were visited in Patchway, Battlefields, Sanyati, Mayflower, Brompton, and Mudzengi in Kadoma, and Wonderer and Chachacha in Shurugwi.

2.2. The Administered Questionnaire

Questionnaires were available in Shona and Ndebele, Appendix A. Shona, the first language of the participants, was used in the administration of the questionnaires by trained and experienced data collectors. Data collectors were trained through a participatory approach as indicated in our separate article, which is based on the same survey [12]. Questions on accidents, injuries, and underground mining were included in the administered questionnaires. Questionnaires were designed based on previous ASGM surveys in Kenya and Zimbabwe [11,41] and were available in Shona and Ndebele. The questionnaires were pre-tested among eight miners from Kadoma and Gwanda in Zimbabwe, and then modified and translated into Ndebele and Shona by experienced translators [12]. The questionnaire was approved along with the study protocol by the Medical Research Council of Zimbabwe [12]. After the participants received the questionnaires, data collectors went through the questionnaires with participants as a group, then participants independently filled out the questionnaires. More support was given as required for participants who had lower literacy abilities and were willing to participate in the study. Participants who were not comfortable participating in the study because of low literacy were not included in the study.

2.3. Data Analysis

Data from the questionnaires were entered, cleaned, and analyzed in SPSS version 20. Categorical data from the questionnaires were summarized using frequencies and percentages as indicated in our separate article based on the same survey [12]. The odds of experiencing injuries and accidents were assessed through cross-tabulation against relevant risks and were presented as unadjusted odds ratios (ORs). The association between experiencing injuries and predictor variables such as age, gender, and workplace roles was assessed using binary logistic regression and was presented as adjusted odds ratios (AORs). The level of significance was set at $p \leq 0.05$.

2.4. Ethical Approval

The study was approved by the University of Munich Ethics Committee (Project 20-068) and the Medical Research Council of Zimbabwe (MRCZ/A/2603) [12]. In addition, consent was sought from local authorities, mine owners, and all participants [12]. Those chosen for the study participated voluntarily and signed the informed consent form prior to data collection. Questionnaires were numbered without names to ensure confidentiality [12]. The data set is available on Mendeley and is accessible upon request.

3. Results

The questionnaires had 401 respondents, with a response rate of 88% as indicated in our separate article based on the same survey [12].

3.1. Socio-Demographic Characteristics

The questionnaires had 401 respondents, for further details on socio-demographic characteristics see Table 1 in our separate article based on the same survey [12]. Seventeen percent of the respondents were women. The proportion of married miners was 51.1%, with more than 50% of the participants between 18 and 36 years old. Education background varied, with 10% receiving tertiary education, 15% had completed primary school, and 7% having no formal schooling. Knowledge and competence in ASGM were low for more than 25% of the survey participants. The migration from site to site was 28%.

The significant roles, mainly taken up by men, included digging, moving ore manually, blasting, and loading ore. Nearly 65% (n = 136) of the miners in Kadoma were involved in digging. More than 30% of the miners worked for more than eight hours per day. Two hundred and one of the participants worked underground. Twenty-seven percent of the participants had up to six months of experience in ASGM and had joined the sector during the COVID-19 pandemic.

Table 1. Socio-demographics: Socio-demographic characteristics of the miners from Kadoma and Shurugwi in Zimbabwe in 2020 (n = 401), modified [12].

Characteristics		***n* (%)**	**Total**
Population per district		401 (100)	401
District *n* (%)	Kadoma	220 (54.9)	
	Shurugwi	181(45.1)	401
Mine category *n* (%)	Rudimentary	78 (19.5)	
	More mechanized	323 (80.5)	401
Sex *n* (%)	Female	69 (17.2)	
	Male	332 (82.8)	401
Marital status *n* (%)	Single	126 (31.9)	
	Married	202 (51.1)	
	Separated	17 (4.3)	
	Divorced	28 (7.1)	
	Widowed	22 (5.6)	395
Age *n* (%)	18–35 years	212 (56.1)	
	36–50 years	130 (34.4)	
	Above 50 years	36 (9.5)	378
Education level *n* (%)	No formal school	28 (7.1)	
	Primary	59 (14.9)	
	Secondary	241 (60.9)	
	Tertiary	39 (9.8)	
	Vocational	29 (7.3)	396
Monthly Earnings *n* (%)	No Earnings	7 (1.9)	
	Less than $100 USD	212 (56.7)	
	Above 100–500 USD	13 (34.8)	
	Above 500–1000 USD	24 (6.4)	
	Above 1000 USD	1 (0.3)	374
Roles *n* (% of cases)	Digging	211 (65.3)	
	Moving ore manually	59 (18.3)	
	Blasting	51 (15.8)	
	Loading	44 (13.6)	
	Washing/panning	33 (10)	
	Cooking	26 (7.9)	
	Amalgam burning	24 (7.3)	
	Milling	24 (7.3)	
	Sponsoring	22 (6.8)	
	Supervision	22 (6.8)	
	Mine owner	19 (5.9)	
	Gold buying	14 (4.3)	549 (Total cases)
Daily working hours *n* (%)	1–8 h	259 (66.9)	
	Above 8–16 h	82 (21.2)	
	Above 16–24 h	46 (11.9)	387
Working underground *n* (%)	Working underground yes	201(52.3)	385
Experience in ASGM *n* (%)	6–12 months	98 (26.7)	367
	>1–5 years	152 (41.4)	
	>5–10 years	57 (15.5)	
	>10–15 years	45 (12.3)	
	>15 years	15(4.1)	
Migration		112 (27.9)	394

3.2. Reported Occupational Safety and Health (OSH)

Of the 401 participants, 198 (49.4%) of the participants reported that they had heard about OSH. Thirty-six percent (n = 138) indicated that they had been trained on (OSH), which was mainly PPE use. Of the 14 participants who indicated their trainers, 11 (78.6) were trained by non-governmental organizations (NGOs) and 3 (21.4%) were trained by community members. However, the prevalence of injuries among the participants who had trained and those not trained was 39% (n = 39) and 34% (n = 84), respectively

(OR 1.2 (0.8–2.0) $p = 0.3$). Training seemingly had no significant impact on the prevalence of accidents and injuries, which could be attributable to the ineffectiveness of training or response bias. The person responsible for safety was reported as mine owner 40.7% ($n = 160$), supervisor 21.9% ($n = 86$), gang leader 12.2% ($n = 48$), employee 21.6% ($n = 85$), and sponsor 3.6% ($n = 14$). There was a form of management and an opportunity for safety management as indicated by the roles of responsibility on safety. However, the common understanding of safety and health was the provision of PPE. PPE was found low and compromised during the same survey [12].

Observed Safety Practices (Observed by Chance during the Survey)

During the survey, one site in Sanyati introduced the wire winch rope. Three sites visited in Kadoma had escape routes. One site in Kadoma had a plan for a waterway to avoid shaft flooding. The mine operation, which had invested in shaft support, had a series of shafts in close proximity to each other, posing the high risk of a major shaft collapse. In addition, one site that was operated by a mining company had gathered timbering wood to transfer mining operations to a new shaft within the same site because of reported high levels of fumes and gasses that had accumulated from blasting. However, there was no knowledge on debarking the timbering wood to reduce the accumulation of gasses. At the same time, the debarking of timbering wood was observed on two sites. Focus group discussions conducted during the same survey indicated that it was expensive for the average ASG miners to invest in mine support, escape routes, and the wire winch rope [12]. Hazard identification and risk assessment were not practiced. The Ministry of Mines and Mining Development was conducting routine inspections mainly on PPE use and there were penalties for non-PPE use, an opportunity for implementation of safety and health management.

3.3. Reported Accidents

Accidents were reported by 140 (35%) miners. Table 2 shows the types of reported accidents and reported occurrences of accidents.

Table 2. Reported types of accidents and associated occurrences of injuries.

Type of Accident	Number (N)	Percentage of Cases	Percentage of Injuries (N)
Slips, trips, and falls (STFs)	43	40.2	52.6(20)
Hit by tools or machines	23	21.4	40.9 (9)
Hit by pieces of stone	28	26.2	50.0(13)
Breaking of winch rope	12	11.2	54.5 (6)
Collapsing	12	11.2	20.0 (2)
Mineshaft collapses	16	15.0	53.3 (8)
Underground trappings	06	5.6%	80.0 (4)

Slips, trips, and falls (STFs), hit by tools or machines, and hit by pieces of stones were the most reported accidents. The mine collapses, underground trappings, and instant deaths were also reported. The study was conducted in the rain season. The mine collapses and STFs could have been associated with the rainy season. During the same survey, breaking of the winch rope was associated with a loss of ability to work; one site had therefore introduced the wire winch rope. However, focus group discussions revealed that the wire winch rope was expensive for an average ASG miner. The types of accidents that were mostly associated with occurrences of injuries were underground trappings, breaking of the winch ropes, and shaft collapses.

Participants indicated that accident reporting could be done to the local chief ($n = 36$, 41.3%), the Ministry of Mines and Mining Development ($n = 112$, 31.5%), the police ($n = 18$, 5.1%), the hospital ($n = 67$, 18.8%), or not reported ($n = 12$, 3.4%). Actions to be taken after an accident included investigation into the cause ($n = 206$, 66%), temporary closure ($n = 70$, 22.4%) of the operation, and no action at all (n = 36, 11.5%). The sites visited had no registers of near-miss incidents and accidents. Accident investigations were not conducted internally by the miners. External investigations were conducted by mine inspectors (the Ministry of Mines and Mining Development) in the event of reported accidents that had associated penalties such as mine closures. Internal accident reporting and incident investigation were therefore not common.

3.4. Reported Injuries

One hundred and three miners indicated that they had been injured at work. The prevalence of injuries in age groups varied from 31.6% (n = 61) for those 18–35, to 26.4% (n = 33) for 36–50-year-old miners, and 16.1% (n = 5) for those over 50 years old (Table 4). Ever-experienced injuries were reported by 71 (38.4%) miners working underground (OR = 3.1 (1.8–5) $p < 0.0001$), which complements findings from the same survey [12]. Rudimentary and more mechanized mining categories reported combined accidents and injuries at 29.2% (n = 21), and 48% (n = 143), respectively (OR = 2.2 [1.3–4] p = 0.004. The type of injuries reported during the same survey were fractures (n = 34, 52.2%), cuts (n = 24, 41.4%), and bruises (n = 22, 37.9%), which results in injuries on hand(s) (n = 38, 28.1%), leg(s) (n = 32, 23.7%), finger(s) (n = 24, 17.8%), head (n = 19, 14.1%), and chest (n = 15, 11.1%) [12].

3.5. Risk Factors

Of the miners who had experienced workplace violence, 39.4% (n = 37) had ever experienced injuries at work (OR = 2.1 (1.3–3.4) p = 005), which complements findings from the same survey [12]. The prevalence of injuries increased with increasing working hours (Figure 2).

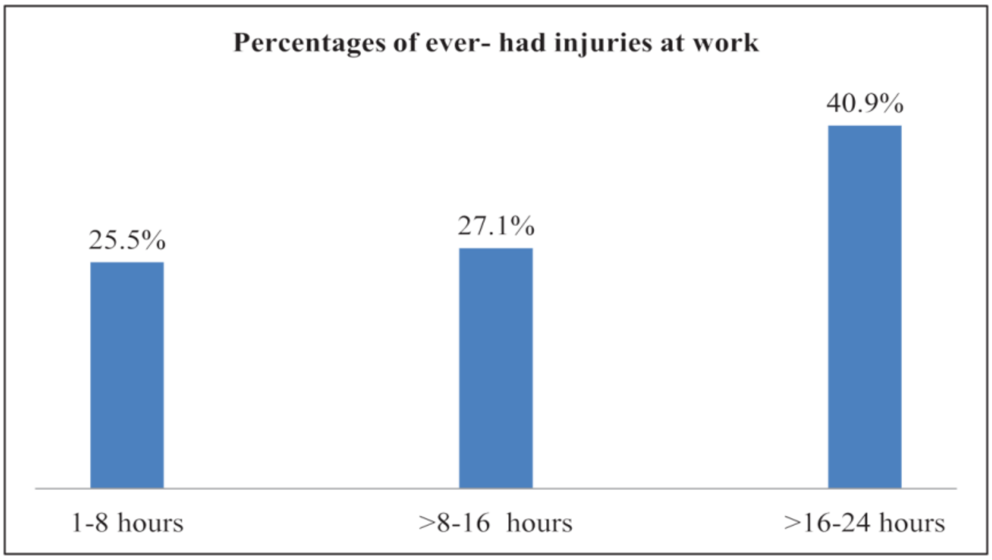

Figure 2. Injuries and daily working hours: Percentages of ever-had injuries at work according to daily working hours reported by miners in Kadoma and Shurugwi, Zimbabwe, in 2020. Total responses: 1–8 h = 243, >8–16 h = 70, and >16–24 h = 44.

Injuries were reported highest among the miners working 16 to 24 h daily. Among the 44 participants who were working for >16–24 h daily, 40.9% (18) had been injured before. Of the miners who were involved in more mechanized and underground mining, 95.7% (n = 44) were working for 16 to 24 h daily. The prevalence of injuries among the artisanal small-scale gold (ASG) miners who were working underground was 57.7% (n = 45) and 65.9% (n = 29) for >8–16 and >16–24 daily working hours, respectively. The distribution of injuries according to experience in ASGM is shown in Figure 3.

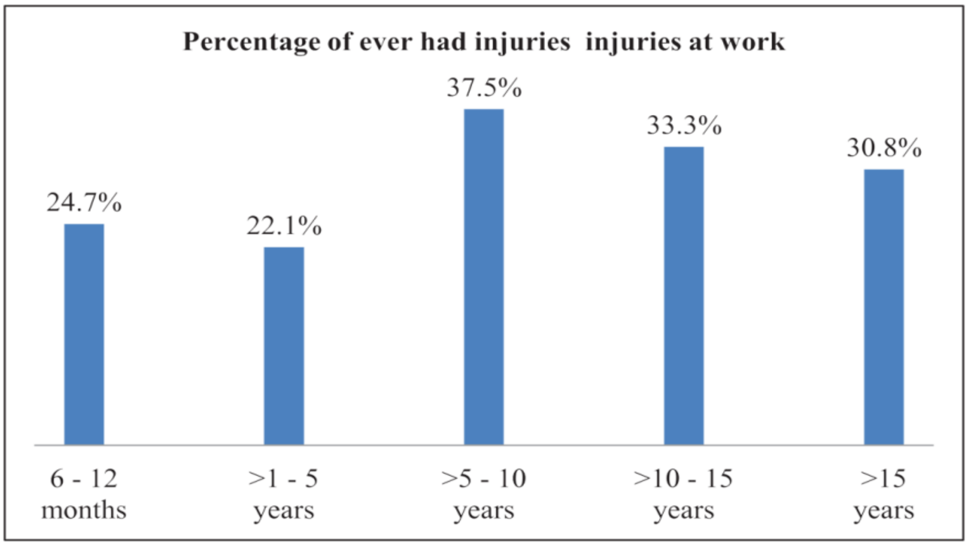

Figure 3. Injuries and years of experience: Percentage of injuries according to experience in ASGM reported by miners in Kadoma and Shurugwi, Zimbabwe, in 2020. Total responses 6–12 months = 93, >1–5 years = 140, >5–10 years = 48, >10–15 = 42, and >15 years = 13.

The injuries decreased to 22.1% (n = 31) from 24.7% (n = 23) after 6–12 months of experience and were more than 30% after more than five years of experience in ASGM, which could be attributable to shifting to more hazardous roles such as blasting with increased experience and lack of training. Due to COVID-19, there were an increased number of new workers without proper training. The regulation on the limited number of workers per site during COVID-19 restrictions could have forced more experienced miners to take on new unfamiliar roles. Training was not associated with decreased prevalence of injuries as presented above. There was no association between experiencing injuries and the level of education or marital status, which could be attributed to response bias. The association between workplace roles and injuries is shown in Table 3.

Table 3. Ever-experienced injuries: Percentages of participants who ever experienced injuries and their workplace roles—as reported by artisanal small-scale gold (ASG) miners from Kadoma and Shurugwi in Zimbabwe in the 2020 rainy season, n = 370.

Role	Total	Ever been Injured		Crude OR (95% CI)	p-Value
		Number	(%) †		
	370	103	25.7%		
Digging					
Yes	196	68	34.7	2.1 (1.3–3.4)	0.02 **
No	174	35	20.1	Reference	
Blasting					
Yes	45	18	40.0	1.8 (0.9–3.6)	0.05 **
No	325	85	26.2	Reference	
Washing/Processing					
Yes	30	10	33.3	1.3 (0.6–3.0)	0.5 (ns)
No	339	93	24.7	Reference	
Moving ore Manually					
Yes	55	27	49.1	3.0 (1.7–5.5)	<0.0001 **
No	315	76	24.1	Reference	
Loading					
Yes	38	18	47.4	2.6 (1.3–5.2)	0.007 **
No	332	85	25.6	Reference	

Table 3. *Cont.*

Role	Total	Ever been Injured		Crude OR (95% CI)	*p*-Value
Sponsoring					
Yes	18	6	33.3	1.3 (0.5–3.6)	0.6 (ns)
No	352	97	27.6	Reference	
Manager/Supervisor/Gang leader					
Yes	20	5	25.0	0.9 (0.3–2.4)	0.7 (ns)
No	350	98	28.0	Reference	
Working at the Mill					
Yes	22	8	36.4	1.5 (0.6–3.7)	0.4 (ns)
No	348	95	27.3	Reference	
Mine Owner					
Yes	15	4	26.7	0.9 (0.3–3)	0.9 (ns)
No	355	99	27.9	Reference	
Amalgam Burning					
Yes	20	7	35.0	1.4 (0.6–3.7)	0.5 (ns)
No	350	96	27.4	Reference	
Cooking					
Yes	22	5	22.7	0.8 (0.3–2.1)	0.6 (ns)
No	348	98	28.8	Reference	
Gold Buying					
Yes	13	5	27.5	1.7 (0.5–5.2)	0.4 (ns)
No	357	98	30.2	Reference	

OR = crude odds ratio; CI = two-sided confidence interval; † = row percentages; ** = statistically significant. ns = non-significant, two-sided chi-square test.

The unadjusted odds of experiencing injuries were at least double for the miners involved in moving ore manually, loading, digging, and blasting. Milling was associated with accidents and loss of fingers during the same survey [12].

3.6. Association between Ever-Had Injuries at Work and Exposure to Risk Factors

Of the 401 miners, 370 participants who responded to the question were included in binary regression analysis; 31 participants did not respond to the question, and 103 (25.7%) had experienced injuries (Table 4). The regression model explained 27% of the variability between exposure to risks and experiencing accidents and injuries (R^2 26.5%, $p < 0.0001$). The association between ever-experienced injuries at work when exposed to risk factors, is shown in Table 4 below.

After adjusting for other variables in the model, the odds of ever-had injuries were more than nine times higher for crushing and blasting. Blasting was associated with mine collapses and fatalities (Table 2). The odds of experiencing injuries were more than four times more for men (AOR = 4.3 (1.4–13.6)) than for women. The likelihood of experiencing injuries was twenty percent more for the 18–35-year age group (AOR = 0.2 (0.07–0.9)) compared to the >50 age group. Simultaneously, the odds of experiencing injuries were five times more during the transportation of miners and ores to and from underground shafts (AOR = 4.9 (2.1–11.2), AOR = 0.04 (0.005–0.3)). Focus group discussions during the same study revealed a tendency to use a worn-out winch rope, which was evidenced by a case of a miner who got injured and lost his ability to work when a worn-out winch was used when he was being transported from the shaft [12]. Miners reported the use of other intoxicating substances, as shown in Figure 4 below.

Among the 97 participants who reported taking intoxicating substances, 89 admitted to alcohol consumption, five used drugs, and marijuana, while three reported a combination of drugs and alcohol use. Alcohol use and smoking were observed on mining sites. One respondent who reported taking marijuana described marijuana as 'mupapfungwa', i.e., wisdom source, a perception that could strengthen drug use in ASGM. No further analysis was conducted on the direction of association between alcohol drugs and injuries, the question on alcohol consumption and drug use was secondary to the question on smoking and there was a low response. Further analysis is recommended for further pieces of research.

Table 4. Ever-been injured at work and exposure to risk factors: Association between ever being injured at work and exposure to risk factors, reported by miners in Kadoma and Shurugwi in Zimbabwe in the 2020 rainy season.

Characteristic	Total	Ever been Injured at Work		OR (95% CI)	AOR = (95% CI)	*p*-Value
		Number	(%) †			
	370	103	(25.7)			
Sex (*n* = 370)						
Male	311	96	(30.9)	1.8 (1.02–3.3) **	4.3 (1.4–13.6)	0.01 **
Female	59	7	(11.5)	Reference	Reference	
Age (*n* = 349)						
>50	31	5	(16.1)	Reference	Reference	
36–50	125	33	(26.4)	0.8(0.5–1.3)	0.7(0.4–1.2)	0.2 (ns)
18–35	193	61	(31.6)	0.4(0.2–1.1)	0.2 (0.07–0.9)	0.03 **
Shaft miners' transportation (*n* = 356)						
Yes	38	22	(57.9)	4.5(2.3–9) **	4.9(2.1–11.2)	<0.001 **
No	318	74	(23.3)	Reference	Reference	
Crushing (*n* = 356)						
Yes	21	14	(66.7)	6.1(2.4–16) **	9.4(2.6–34.0)	0.001 **
No	335	82	(24.5)	Reference	Reference	
Blasting (*n* = 356)						
Yes	17	10	(58.8)	4.2(1.6–11.3) **	9.2(2.6–33.0)	0.001 **
No	339	86	(25.4)	Reference	Reference	
Flying stone particles (*n* = 350)						
Yes	26	13	(26.9)	2.7(1.2–6.1) **	2.1(0.5–8.1)	0.3 (ns)
No	324	87	(31.7)	Reference	Reference	
Removing ore from the shaft (*n* = 356)						
Yes	14	4	(28.6)	1.1(0.3–3.6)	0.04(0.005–0.3)	0.002 **
No	342	92	(26.9)	Reference	Reference	
Working tools and machines (*n* = 350)						
Yes	22	9	(40.9)	1.8(0.7–4.4)	2.2(0.6–8.4)	0.3 (ns)
No	328	91	(27.3)	Reference	Reference	

AOR = adjusted odds ratio; CI = two-sided confidence interval; † = row percentages; ** = statistically significant. ns = non-significant, two-sided chi-square test.

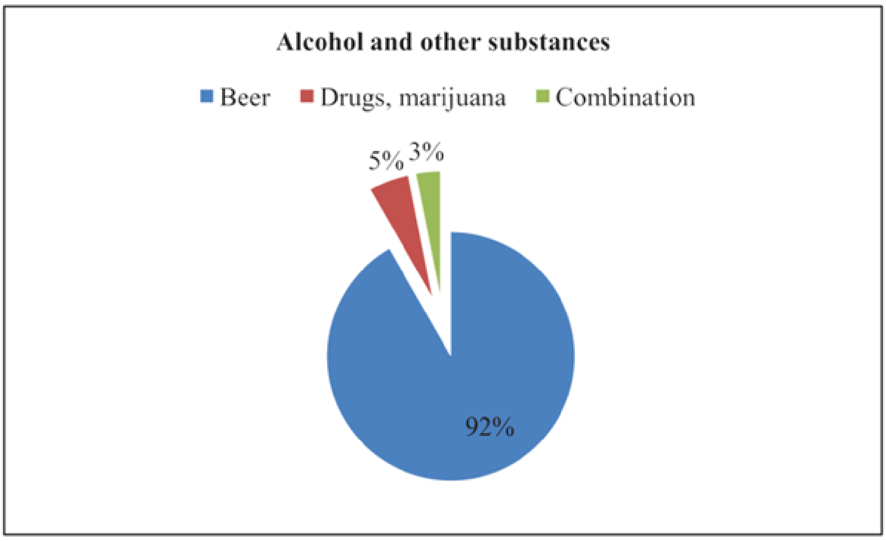

Figure 4. Alcohol and drug consumption: distribution of alcohol and drug use reported by ASG miners in Kadoma and Shurugwi in the 2020 rainy season, *n* = 97.

4. Discussion

This cross-sectional survey found the prevalence of accidents and injuries in ASGM in Zimbabwe at 35.0%, and 25.7%, respectively. Accidents that had high risks of experiencing injuries were slips, trips, and falls (STFs), flying particles, mine shaft collapses, and underground trappings. STFs and mine collapses were common in the rainy season. The majority of the participants had heard of OSH, which was mainly PPE use. Training and routine inspection on PPE use was found. Mine owners, supervisors, employees, and sponsors were reported as responsible for OSH, which was mainly PPE use, an opportunity for risk management. The associated risks included long working hours, alcohol and drug abuse, and underground mining. The other factors associated with a high risk of experiencing injuries were being male, being in the age group 18–35 years, digging, blasting, loading, the transportation of miners and materials from shafts, and crushing. Figure 1 illustrates different settings of high exposure to hazards, reduced exposure to hazards, and comprehensive protection. ASGM in Zimbabwe is characterized by high exposure to hazards [11,12,15]. This section discusses the prevalence of accidents and injuries, the associated risk factors, and the opportunities to improve safety in ASGM to achieve reduced exposure to hazards and comprehensive protection.

During the cross-sectional survey, 35.0% of the participants reported ever-experienced accidents at work, which is comparable to similar studies. For example, 32.9% of respondents in the DRC's ASM reported accidents when handling heavy loads [8]. The odds of experiencing accidents and injuries were more than double for more mechanized mining operations compared to rudimentary operations, which could be attributed to long working hours and underground mining, without successive layers of control measures as further discussed below. Alcohol consumption and drug use at work were common with no control measures, this concurs with previous literature [11,12,15]. Working under the influence of alcohol and drugs is a significant determinant of accidents and injuries in ASM [8,16]. In Kenya, the prevalence of accidents in ASGM was found to be higher among high-risk drug users, 34.2% (n = 25) compared to non-drug users 13.6% (n = 11) (p = 0.001) [16]. There was a perception that drug use at work instilled wisdom among ASG miners, a harmful myth that could strengthen risky behavior in Zimbabwe's ASGM [32]. Hence, the need to reduce exposure of ASGM to hazards through relevant public health interventions such as peer counseling and awareness raising to mitigate the risk of workplace alcohol consumption and drug use.

The prevalence of ever-experienced injuries, i.e., 25.7%, surpassed Zimbabwe's 2019 LSM rate of 6.7 per 1000, which was based on claims from LSM corporations that were submitted to NSSA [3]. LSM workers also receive health and social security coverage, while such services are not accessible for workers in Zimbabwe's ASGM [11,12]. Outside of Zimbabwe, ASGM injuries are also much higher than those working in LSM [6], as seen in Ghana, where approximated injury rates were 45.5 per 100 persons in 2011 and 38.5 per 100 person-years in 2013 [9]. The odds of experiencing injuries were higher for men than women while the prevalence of injuries decreased with age, confirming previous findings [10]. Since the 18–35 age group was at a higher risk of experiencing injuries, the higher proportion of ASG miners aged 18–35 during the survey implies an increased prevalence of injuries in Zimbabwe's ASGM during the study period.

Underground artisanal mining is commonplace in Zimbabwe. This type of mining requires more technical processes, such as mine support, drilling, blasting, and loading [18], and is associated with increased risks compared to surface mining [18,19]. Injury risk factors associated with underground mining included long working hours, more mechanized mining processes, and high-risk roles, which resulted in increased odds of experiencing injuries, echoing existing literature [8,12,18,19]. In Kenya, the miners' odds of experiencing injuries were 2.6 (p = 0.002) times higher for those working more than eight hours per day compared to the miners working for less than eight hours per day [16]. Workers with high-risk underground mining roles, i.e., blasting, crushing, loading, and underground transportation of people and materials to and from underground shafts had increased odds of experiencing injuries (as documented in previous literature) [18,31]. In Ghana, mine pit collapse was the most frequent cause of accidents associated with injuries, followed by blasting injuries [10]. Ground failures, due to unsupported or poorly supported shafts and poor pit design, also led to fatalities and injuries of varying degrees in Ghana ASM operations [19]. The ground failures were attributed to a lack of planning, the unfamiliarity with rock strength and stability, and an incorrect choice of mining methods stemming from a lack of technical knowledge and experience [19]. Mine support is therefore defined as one of the top priorities in mining safety [18]. However, artisanal, and small-scale underground mining is usually associated with sub-standard mine support [11,12,15,19]. While the mining regulations have set the standards for underground mine support, substandard and unsafe mining pits are common in Zimbabwe's ASGM [11,12,15]. As presented above, there is a need for adaptable ASM regulations, as well as technical support, as further presented.

Since underground ASGM mining is a high-risk sector and ASGM in Zimbabwe is associated with injuries and fatalities [7,10,17–20,32], there is a need for accident prevention control measures to reduce exposure of ASG miners to associated risks. Internal hazard identification and risk assessment and incident reporting and investigation were not found in this study. Hazard identification and risk assessment is the initial step toward risk control, which guides the development of prevention strategies [35]. Furthermore, for every fatal accident, there are 10 serious accidents, 30 minor accidents, and 600 near-misses, 1:10:30:600 [42]. Apparently, accident investigations were conducted by mine inspectors and were associated with penalties. Accident reporting was therefore not common. The behavior of concentrating on one fatality while neglecting 600 near-misses, which provide the opportunity to prevent the fatality, is harmful [34]. Hence the importance of an internal incident investigation that focuses on near-misses (six hundred near misses to prevent the fatality) for accident prevention in ASGM in Zimbabwe. The motivation of the sector could facilitate the uptake of such safe practices, thereby reducing exposure to hazards. The business and market-centered approach has been used to improve returns and incentivise and motivate protective safe practices in ASGM [43,44].

In addition to compromised PPE use, training is fundamental to reducing weaknesses in individual control measures and establishing successive defense layers of protection. A low competence in mining was found as demonstrated by a lack of knowledge on mine support. In addition, longer work experience was not associated with a lower prevalence of injuries, which confirms previous findings [10] that attribute a lack of training and exposure to riskier roles, such as blasting, with increased ASGM experience. Low levels of literacy and limited knowledge on mining are common among ASGM miners [5,7]. However, in Ethiopia, increasing work experience was associated with decreasing non-fatal injuries [13]. This research was conducted during the COVID-19 pandemic and so this was a time that could have witnessed more experienced workers forced to take on new and unfamiliar roles due to restrictions on the number of workers allowed per site. Simultaneously, a lack of training is also common in artisanal and small-scale mining (ASM), as is confirmed in DRC where a lack of training was also found to be one of the determinants of accidents in ASM [8]. Although some participants indicated that they had trained on PPE, there was no association between training and a reduced prevalence of accidents. The training was mainly conducted by NGOs. Continual technical training on safety is therefore one of the potential control measures to improve safety in ASGM in Zimbabwe. Pact developed a user-friendly training handbook for ASM for Zimbabwe with specific modules on underground mine support as well as safety and health [45]. Training in ASGM could also be conducted through the Ministry of Mines and Mining Development and the Mining Institutions, in addition to NGOs. However, training is a cost that requires a budget. Furthermore, the migratory nature of the unregistered ASG miners and the lack of sufficient capital for training and implementation of safe mining standards could threaten the effectiveness of training initiatives. Hence, the need for formalizing, regulating, and financing the sector is discussed further below.

Mitigation controls are relevant to Zimbabwe's ASGM. Mine collapses and underground trappings were reported, which confirms previous literature [7,12,17]. Although the odds of experiencing accidents and injuries are generally higher in ASGM compared to LSM [6], ASGM miners in Zimbabwe are exposed to accidents and injuries with limited access to health care services and medical and social security insurance coverage [11,12,15]. Research on small enterprises involving young workers has shown that the cost of occupational injuries, diseases, and deaths on the employee (ASGM miner), the employer, and the community is 77%, 5%, and 18%, respectively [23]. Risk management reduces the time lost to injuries and associated medical costs with a positive impact on maximizing economic benefits in mining [22]; hence, improving the safety of ASGM miners is likely to be associated with improved production and positive safety outcomes. Therefore, all concerned parties will benefit from improved comprehensive risk management in ASGM in Zimbabwe. An expanded health and social security insurance coverage for Zimbabwe's ASG miners is therefore required to reduce the adverse impacts of accidents and injuries for the miners, and the mining communities [12].

The study revealed opportunities and threats for safety management in ASGM. The majority of the participants had heard of PPE use. Training on PPE, routine inspections, management, and external accident investigations were found. Furthermore, there were positive attempts toward safe practices by a few miners. Hence, the opportunity for safety and health management. Current efforts to improve safety in ASGM focus on strengthening PPE. However, PPE is the least effective control measure for mine safety [26], as PPE cannot mitigate the risk of a mine collapse [12,18]. In addition to PPE use, shaft support is a priority for underground excavations [18]. Although the mining regulations for Zimbabwe stipulate safety standards [36], which can result in successive layers [27] of the hierarchy of controls [26], compliance was limited in ASGM [11,12,15] because of the low financial capacity and the dynamic nature of the sector [37,38]. Formalisation and regulation [39] of the sector are therefore prerequisites for the effective implementation of relevant regulations. In Mongolia for example, the ASM legal framework paved the way for the formalization of ASM, the enforcement of relevant health and safety regulations, as well as the implementation of global initiatives such as the *Fairmined gold initiative* and responsible mining standards that strengthened risk management and allowed the introduction of successive control measures, thereby providing the opportunity for comprehensive protection in ASGM [43,44]. Hence, the relevance of the ASM legal framework that addresses the safety needs of the ASGM sector in Zimbabwe.

Limitations and Strengths

Data from the questionnaires were self-reported; recall bias, response bias, and social desirability were inevitable. Participants with low levels of literacy who were not comfortable filling in the questionnaires with support were not included in the study. Odds ratios on workplace roles did not account for confounding factors such as stress and individual health status. Data should therefore be interpreted with caution. Concurrently, self-reporting has been used successfully in social research [46] to inform decision-making and guide further research. This study, therefore, gives an overview of the prevalence of accidents and injuries and the associated risk factors. This overview could guide relevant initiatives and further research in Zimbabwe's ASGM, and ASGM in general. The study could therefore contribute substantially to ongoing research on safety in ASGM, both locally in Zimbabwe and globally.

5. Conclusions

Artisanal and small-scale gold mining (ASGM) miners in Zimbabwe are faced with occurrences of accidents and injuries. Accidents and injuries were associated with underground mining, long working hours, being 18–35 years old, and being male. Underground mining was associated with high-risk activities such as blasting and the transportation of workers and materials to and from underground shafts, which was common with more mechanized mining methods. Alcohol consumption at work and drug abuse was reported. Participants had heard of PPE. There was training and inspection on PPE use. Few individual miners were introducing shaft support in hazardous ways and/or without technical support. Safety practices including shaft support, accident investigation, hazard identification, and risk assessment were missing. Mining regulations, which would provide for a range of control and safety measures, could not be adapted to the ASGM method in Zimbabwe.

Recommendations

As indicated by Smith, ASGM should be prioritized as a high-risk sector [30] and we recommend: (i) Relevant and adaptable health and safety regulations for ASGM in Zimbabwe. (ii) Formalisation, regulation, and relevant financing schemes to improve safety in ASGM. (iii) Interventions on raising awareness on risk factors and benefits of safety practices. (iii) The identified opportunities can facilitate training on effective control measures through establishing demonstration sites. (iii) The Ministry of Health and Child Care should prioritize out-scaling national public health interventions on counseling and raising awareness of the adverse impacts of alcohol consumption and drug use in ASGM communities. (iv) ASGM associations, ASGM miners, and relevant stakeholders need to advocate for health insurance and social security for ASGM.

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Informed Consent Statement: Participants signed the informed consent before filling out the questionnaire.

Data Availability Statement: Data are available at: Singo, Josephine (2022), "Health Challenges and Risk Factors in ASGM in Zimbabwe: 2020 Survey", Mendeley Data, V1, doi:10.17632/55vx7wjwhn.1. [47].

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Appendix A

Questionnaires (Designed based on previous ASGM surveys in Kenya and Zimbabwe [11,42].

Assessment of the safety and health of workers and the relevant Occupational Safety & Health Management System in the Informal Sector: A Case of Artisanal and Small Scale Gold Mining in Zimbabwe and Uganda.

Site..................................Category:.....................................Date....................................

Section 1: General Worker Information	
1. Gender	$_1$ Female $_2$ Male
2. Age	$_1$ 18–35 $_2$ 36–50 $_3$ >50 $_{777}$ Other Specify ___________ $_{999}$ Refuse to answer
3. Highest level of education	$_1$ No formal school $_2$ Primary $_3$ Secondary $_4$ Tertiary $_5$ Vocational $_{777}$ Other Specify ______________________ $_{999}$ Refuse to answer
4. Knowledge and competence of your work in artisanal mining	$_1$ Low $_2$ Average $_3$ High $_{777}$ Other Specify________ $_{888}$ Don't Know $_{999}$ Refuse to answer
5. Marital status	$_1$ Single $_2$ Married $_3$ Separated $_4$Divorced $_5$ Widowed $_{999}$ Refuse to answer
6. Household size (Number of people staying within your family)	$_1$ 1 $_2$ 2–5 $_3$ More than 5 $_{777}$ Other, Specify ________________ $_{999}$ Refuse to answer
7. Which assets have you owned through ASGM	$_1$ Television $_2$ Car $_3$ Radio $_4$ Bicycle $_5$ Smart phone $_6$ House $_{777}$ Other, Specify ____ $_{999}$ Refuse to answer
8. Monthly household income	$_1$ 100 USD and less $_2$ 100–500 USD $_3$ 500 USD-1000 USD $_{777}$ Other, Specify _______ $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer
9. Have you moved and worked in different mining sites in the past 6 months	$_0$ No $_1$ Yes $_{789}$ N/A $_{999}$ Refuse to answer If yes, please indicate why ....
10. Which department do you work in?	$_1$ Digging $_2$ Blaster Blasting Licence $_0$ No $_1$ Yes $_{777}$ Other, Specify _______ $_3$ Lashing $_4$ Washing $_5$ Carrying/moving mined ore to the surface $_6$ Loading/off when transporting ore to the stamp mill $_7$ Sponsor $_8$Manager/Supervisor/Gang leader $_9$ $_W$orking at the Stamp Mill $_{10}$ Mine Owner $_{11}$ Amalgam burning $_{12}$Cooking $_{13}$Carrying ore manually to the stamp mill $_{14}$ Gold buying $_{777}$ Other, specify _____ $_{888}$ Don't Know $_{999}$ Refuse to answer $_{789}$ N/A (a) Do you work underground? a $_0$ No $_1$ Yes $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer (b) If yes do you work alone? a 0 No $_1$ Yes 789 N/A $_{888}$ Don't Know $_{999}$ Refuse to answer (c) How many hours do you work in a day? a $_1$ 1–8 $_2$ 9–16 $_3$ 17–24 $_{888}$ Don't Know $_{999}$ Refuse to answer (d) What kind of working arrangement do you have a $_1$ Salary $_2$ Shares $_3$ Contractor $_{777}$ Other, specify _____ b $_{888}$ Don't Know $_{999}$ Refuse to answer
11. How long have you worked in artisanal and small scale gold mining?	$_1$ 1–5 years $_2$ 6–10 years $_3$ 11–15 years $_4$ >15 $_{789}$ N/A $_{666}$ Don't Remember $_{999}$ Refuse to answer
12(a). Do you know of HIV/AIDS test center close to your work place	$_0$ No $_1$Yes $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer (b) Have you ever taken HIV test? $_0$ No $_1$ Yes $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refused to answer (c) If yes and you are comfortable, may you share your status? $_0$ Negative $_1$ Positive 789 N/A 888 Don't Know 1010 Uncomfortable to answer
13(a). Have you ever experienced any health problems, became sick or got injured because of mining activities?	$_0$ No $_1$ Yes (b) If yes, please specify, $_1$ Respiratory problem $_2$ Memory problems $_3$ Skin problems $_4$ Reproductive problems $_5$ Hearing problems $_6$ Musculoskeletal Problems $_7$ Kidney problem $_8$ Sight problems $_9$ Digestive problems $_{10}$Stress $_{11}$ Injury $_{777}$ Other Specify ______ $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer

14. How would you rate your health today from 1 to 100? 1 is the worst 100 is the best health state______	
Section 2 Occupational Safety	
15. Who is responsible for safety on your site	$_{1}$ Mine Owner (on site) $_{2}$ Supervisor $_{3}$ Gang leader $_{4}$ Employee $_{777}$ Other Specify__________ $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer
16(a). Have you ever had safety issues at your workplace	$_{0}$ No $_{1}$ Yes (b) If yes, in which department/area? $_{1}$ Going down to the mine/returning to the ground $_{2}$ Excavation $_{3}$ Blasting $_{4}$ Lashing $_{5}$ Crushing $_{6}$ Removal of ore from shafts $_{7}$ Milling $_{8}$ Sluicing $_{9}$ Loading, carrying of ore to the mill and off loading $_{10}$ Amalgam burning $_{11}$ Delivery and selling of gold $_{12}$ Acquisition and delivery of equipment and chemicals $_{13}$ Storage of equipment and chemicals $_{14}$ Disposal of waste $_{777}$ Other, specify _________ $_{789}$ N/A $_{666}$ Don't Remember $_{999}$ Refuse to answer (c) What was the safety issue? $_{1}$ Slipping /tripping/ falling $_{2}$ Hit by working tools/machines $_{3}$ Instant death $_{4}$ Hit by pieces of stone $_{5}$ Breaking rope (hoist) $_{6}$ Collapsing $_{7}$ Mine shaft collapse $_{8}$ Failing to breath $_{9}$ Trapped underground $_{999}$ Refuse to answer $_{777}$ Other, Specify_______________ $_{789}$ N/A $_{888}$ Don't Know
17. When an accident occurs at work how is it handled?	$_{1}$ Reported to area chief $_{2}$ Reported to County Director of Mines $_{3}$ Reported to Country Commissioner $_{4}$Not reported $_{5}$ Reported to the hospital $_{777}$ Other Specify_______________ $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer
18. What actions are normally taken after an accident?	$_{1}$ Investigation into the cause $_{2}$ Temporary Mine closure $_{3}$ None $_{777}$ Other, specify _______________ $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer
19(a). Have you ever been injured in the course of your work?	$_{0}$ No $_{1}$ Yes (b) If yes, what was the type of injury? $_{1}$ Cuts $_{2}$ Fractures $_{3}$ Bruises $_{4}$ Back/Chest injuries $_{777}$ Other, specify__________ $_{789}$ N/A $_{666}$ Don't Remember $_{999}$ Refuse to answer
20(a). What was the cause of the injury?	$_{1}$ Struck/hit by rock $_{2}$ Sharp (rock) edges $_{3}$ Fall $_{4}$ Vibration $_{5}$ Working tools/Machinery $_{6}$ Lifting heavy load $_{7}$ Awkward posture $_{777}$ Other, specify ________ $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer (b) Which part of your body was injured $_{1}$ Head $_{2}$ Legs $_{3}$ knee $_{4}$Feet $_{5}$ Back $_{6}$ Chest $_{7}$ Hand $_{8}$ Palm $_{777}$ Other, specify_______________ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer (c) Do you have access to compensation $_{0}$ No $_{1}$ Yes $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer $_{777}$ Other, Specify_______________ (d) Do you have access to health care insurance $_{0}$ No $_{1}$ Yes $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer $_{777}$ Other, Specify_______________
21(a). Have you ever heard about workplace safety and health?	No $_{0}$ $_{1}$Yes (b) If yes, where did you get the information? $_{1}$ Fellow miner $_{2}$ Mine Site Manager $_{3}$ Radio/TV $_{4}$ Friend/Family $_{5}$ Social media (Facebook/Twitter) $_{6}$ Newspaper/Magazine $_{7}$ Training $_{789}$ N/A $_{777}$ Other, specify________ $_{666}$ Don't Remember $_{999}$ Refuse to answer

22(a). Do you use personal protective equipment (PPE) when working?	No $_0$ $_1$ Yes (b) If yes, which PPE? $_1$ Helmets $_2$ Protective footwear $_3$ Protective glasses /face masks $_4$ Protective clothing(jackets) $_5$ Ear protection $_6$ Dust mask $_7$ Respirators $_8$ Protective belt $_9$ Sunhat $_{10}$ Raincoats $_{777}$ Other, specify ______________ $_{789}$ N/A $_{999}$ Refuse to answer (c) How did you get the PPE? $_1$ Provided by site manager $_2$ Bought for myself $_3$ Given by co-worker $_4$ Given by a friend/family $_{777}$ Other, Specify__________ $_{789}$ N/A $_{999}$ Refuse to answer (d) How often do you replace your PPE (dust masks, ear plugs, etc.)? $_1$ Frequently $_2$ Rarely $_3$ Never $_{789}$ N/A $_{999}$ Refuse to answer (e) What are the common reasons for not using Personal Protective Equipment? $_1$ Not provided $_2$ Not required $_3$ Not comfortable $_4$ Not affordable $_5$ Not aware of their importance $_{789}$ N/A $_{888}$ Don't Know $_{777}$ Other, specify______________ $_{999}$ Refuse to answer
23. Have you ever experienced a case(s) of violence related to your work?	$_0$ No $_1$ Yes $_{888}$ Don't Remember If yes, what kind of violence $_1$ People taking over shafts by force $_2$ Raiding of ore, gold, equipment etc. $_3$ Physical attacks $_4$ Fights at work $_5$ Gender based violence $_{777}$ Other [Specify] ____________________________________
23(a). Have you ever been trained on OSH and/or first aid?	OSH $_0$ No $_1$ Yes First Aid $_0$ No $_1$ Yes (b) If yes, who was the trainer? $_1$ Mine/Site Manager(supervisor) $_2$ Safety expert $_3$ Workmate $_4$ NGO $_{777}$ Other, Specify______________ $_{789}$ N/A $_{999}$ Refuse to answer
24. Which services do you have access to	$_1$ Occupational Safety and Health training $_2$ Financial support $_3$ Mining services $_4$ Shops with PPE $_5$ Health Care $_6$ Social security $_7$ Emergency Services $_8$ Competitive gold markets $_9$ Schools $_{10}$ Partnerships/Associations $_{11}$ Communication Specify Telephone Radio Television $_9$ Newspaper Social Media Community Gatherings $_{777}$ Other services, Specify_______ $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer
25. What do you consider the priority safety and health issues at your work place?	$_1$ Dust $_2$ Noise $_3$ Flooding $_4$ Injuries/accidents $_5$ Hot confined shaft $_6$ Workplace Violence $_7$Muscle and back pain $_8$ Explosive fumes $_9$ TB $_{10}$HIV $_{11}$Mercury burning $_{12}$Malaria $_{13}$Snakes $_{14}$ Hunger $_{15}$ Diarrheal diseases $_{16}$ Heat Stress $_{17}$ Cyanide $_{777}$ Other, Specify _____ $_{789}$ N/A $_{888}$ Don't Know $_{999}$ Refuse to answer
Section 3. Standard Operating Procedures	
26. Do you have specific ways of working safe before during or after when performing activities like entering the mining pit, drilling, working with explosives lashing after blasting with explosives, manual lifting or carrying heavy loads, burning amalgam, milling or tanks/ cyanidation	$_0$ No $_1$ Yes $_{888}$ Don't Know If yes, please list them here____ ____ ____ ____ ____ ____ ____ ____

Section 4. Gendered Challenges	
1-2 27. Would you indicate roles for men and women in the following activities Male Female Both	Prospecting (prospector/sampler) Male Female Both Digging Male Female Both Drilling Male Female Both Blasting Male Female Both Lashing Male Female Both Transportation of ore Male Female Both Crushing Male Female Both Milling Male Female Both Sluicing Male Female Both Washing/Panning Male Female Both Amalgamation Male Female Both Cyanidation Male Female Both
1-2 28. Are there workplace challenges/difficulties common for men or women at your work?	Men $_0$ No $_1$ Yes Women $_0$ No $_1$ Yes If yes, please specify: Men____ ____ ____ If yes, please specify: Women ____________

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Health and Safety Risk Mitigation among Artisanal and Small-Scale Gold Miners in Zimbabwe

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Abstract: Artisanal and small-scale gold mining (ASGM) is often associated with no or compromised attention to health and safety. Although headlines of fatal accidents in Zimbabwe characterise ASGM, little attention is paid to prevention strategies. This study, therefore, explores health and safety risk mitigation in ASGM in Zimbabwe to inform prevention strategies. A qualitative design was used with focus group discussions and in-depth interviews. Data were analysed using thematic analysis, coding, and descriptive statistics. Reported factors contributing to compromised health and safety included immediate causes, workplace factors, ASM related factors, and contextual factors, with interconnectedness between the causal factors. In addition, factors related to ASGM were significant. For risk mitigation, formalisation, organisation of risk reduction, behaviour change, and enforcement of prevention strategies is proposed. A multi-causal analysis is recommended for risk assessment and accident investigation. A multi-stakeholder approach could be considered for risk mitigation including community and public health interventions. However, risk mitigation has been characterised by gaps and weaknesses such as lacking ASM policy, lack of capital, poor enforcement, negative perceptions, and non-compliance. Therefore, we recommend addressing the threats associated with health and safety mitigation to ensure health and safety protection in ASGM.

Keywords: artisanal and small-scale gold mining (ASGM); artisanal and small-scale mining (ASM); Zimbabwe; multi-causal analysis; health; safety; multi-stakeholder risk mitigation; large-scale and small-scale mining collaboration; community and public health interventions; mitigation measures

1. Introduction

Mining is a hazardous occupation, accounting for 1% of the global workforce and 8% of fatal occupational accidents, with more people employed in artisanal and small-scale mining (ASM) than large-scale mining (LSM) [1]. In Zimbabwe, the zero-harm policy [2] targets the formal sector, which includes LSM and excludes the informal sector, e.g., ASM. Artisanal and small-scale gold mining (ASGM) is a branch of ASM that extracts gold. This study refers to both ASM and ASGM. The number of people working in ASGM worldwide is estimated at 14–19 million [3]. In Zimbabwe, more than 500,000 people are informally employed in ASM [4], mainly in ASGM. Furthermore, ASGM is often informal, undercapitalized, and characterised by little or no mining knowledge and limited capacity to comply with international or national health and safety regulations [1,5,6]. As a result, the number of occupational accidents in ASGM worldwide is six to seven times higher than in LSM [1].

In 2020, 5000 deaths from ASM were reported worldwide, while Zimbabwe had 42 deaths, based on an online media data set [5]. In addition, our previous articles revealed reported occurrences of health and safety problems (45%) [7], accidents (35%) and injuries (26%) [8]. The health and safety problems included respiratory (n = 33, 26.6%), musculoskeletal (n = 29, 23%), stress (n = 28, 23%), hearing (n = 11, 8%), and reproductive (n = 4, 3%) challenges [7] with little or no access to health care services [7–10]. Occupational injuries and health risks in mining negatively impact miners, their families, and ASGM communities [5–11]. The range of control measures from most protective to least protective consist of elimination, substitution, engineering, administrative controls, and PPE [12]. While most fatalities in ASM are preventable [6], preventive measures such as engineering controls, accident investigations, and consistent risk management are scarce in ASGM [7,8,13–15].

Fatalities are preventable if the causes of serious accidents, minor accidents, and near misses are investigated and managed [16]. Accident investigation involves determining the cause of an accident through risk assessment, followed by enforcement of measures to prevent future accidents [17]. Accident investigation has resulted in a significant reduction in accidents and fatalities in LSM [17]. Reason (2016) developed the Swiss cheese model for organisational accident risk management, which illustrates the causal factors of accidents (in high-technology systems) as unsafe acts, local workplace factors, and organisational factors [18]. Although Reason's model (2016) is popular for identifying causes of accidents in manufacturing, it was found to be inadequate for different workplace settings [19]. Therefore, Bonsu (2017) modified the Swiss cheese model to include barrier analysis (existing control measures), meta-analysis (other factors), and causal analysis and applied the model to the study of mining accidents. [19]. However, ASGM is often associated with little or no consideration for health and safety [1,5,6,20]. Barriers to risk reduction in ASGM include ignorance, individual personalities, inherent informal practices, and financial constraints [5,6,15,21–24]. Figure 1 shows the contributing factors to hazards in ASGM and the actions that could mitigate health and safety risks in ASGM.

Figure 1a illustrates the immediate and underlying causes of compromised health and safety in ASGM. Figure 1b suggests mitigation measures including formalisation (incorporating financing and regulation of the sector), health and safety organisation, behaviour change, and enforcement through multi-stakeholder synergy including LSM-ASM public health and community collaborations and interventions. Proposed mitigation layers are dependent on human effort [12], hence each layer is characterised by numerous weaknesses symbolised by 'holes' as in the Swiss Cheese model [25], gaps such as the lack of resources, deficiencies in ASM policies, poor enforcement, unsafe equipment, hazardous work environment, poor supervision, and negative perceptions [5,15,21,24,26]. According to Reason (2000), the 'holes' in protective layers open and close in response to prevailing circumstances [25]. Therefore, efforts should be made to minimise gaps and weaknesses in each defence layer to protect health and safety in ASGM [8]. A single protective layer could increase the likelihood of accidents, injuries, and poor health [7,8], while an additional protective layer may improve protection of miners in ASGM [8]; see Figure S1. Figure S1D [8] assumes significant reduction of deficiencies through successive and effective control measures during health and safety mitigation in ASGM [8].

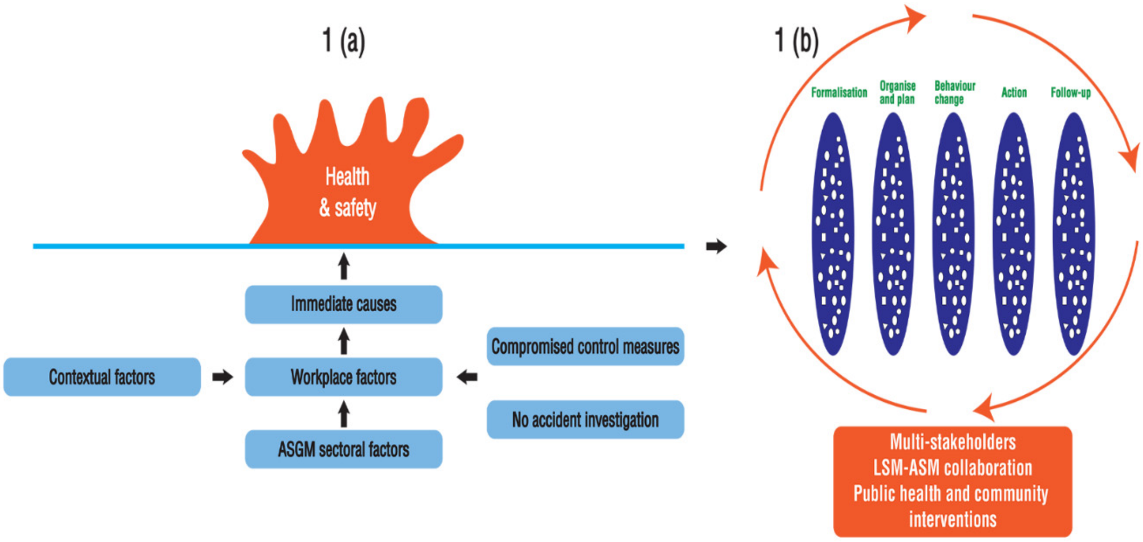

Figure 1. Multi-causal analysis and multi-stakeholder risk mitigation framework for health and safety in ASGM. (**a**) Multi-causal analysis to identify factors contributing to compromised health and safety in ASGM. (**b**) Multi-stakeholder risk mitigation framework for health and safety in ASGM. Source: Own.

Immediate causes are defined as unsafe actions and human error [18]. In addition, Bonsu (2017) included non-human causes such as equipment failure [19] in the Swiss cheese model. Therefore, in this study, human errors such as mistakes, non-compliance, human behaviour, and non-human causes (i.e., equipment) are defined as immediate causes.

Workplace risk factors are workplace conditions that can cause accidents [18], e.g., incompetence, inappropriate equipment, unsafe work practices, hazardous work environments, and noise levels that lead to accidents [18,19].

ASGM-related factors are the inherent causal factors associated with ASGM. For example, informal practices prevalent in the ASM sector, such as lack of regulation, lack of financing, low levels of education, insufficient capital, and lack of health and safety management [1,5,6,11,13,21], could contribute to deficiencies in best practices in health and safety mitigation. In addition, the Nigerian ASM sector's lack of adequate information has been identified [23]. These shortcomings can thus contribute to accidents and poor health in the sector.

Contextual factors include those surrounding the incident, such as time of day, task, and seasonal changes, as well as external factors, such as the COVID-19 pandemic, also known as 'metadata' [19].

Comprehensive control measures are not standard in ASM [6,14,21,22]. An analysis of hazards and controls in ASGM revealed a lack of engineering controls as well as weaknesses in risk mitigation, including compromised use of PPE [7]. Compromised and inadequate control measures could lead to accidents, injuries, and ill-health in ASGM [6–8,11,24].

Risk assessment should be followed by risk mitigation, and a lack of effective risk mitigation leads to serious workplace accidents [17,27,28]. The plan-do-check-act (PDCA) method, which focuses on continuous improvement of health and safety, has been applied in the formal sector (including LSM in Zimbabwe [28]), which is characterised by conventional management systems [27,28]. In contrast, prevailing informal conditions in ASM, such as lack of financing and health and safety management [6,13,29,30], may challenge the applicability of the PDCA in ASGM.

Scholars have argued that ASM's lack of regulatory oversight [30,31] hinders risk mitigation [6,13,21] in the sector. Therefore, there is the need to formalise the sector (Figure 1b) by adapting ASM policies, regulating and financing the sector [6,29,31]. The organisation of health and safety management (Figure 1b) incorporates defining roles, planning, and implementing health and safety risk mitigation measures (e.g., risk assessment, risk mitigation and training [27,32].

In addition, ASGM is characterised by negative workplace behaviour that leads to unsafe actions such as mining shaft pillars, non-compliance with the recommended post-blasting waiting period, and poor compliance with PPE use [6,13,24]. Behaviour is therefore a key predictor of workplace safety and health [24,25,28,33]. Figure 1b suggests behaviour change among risk reduction measures for ASGM. The behaviour change wheel identifies capability, opportunity, and motivation as prerequisites for behaviour change [34]. At the same time, safety behaviour change is influenced by workplace organisation, context, and existing systems [33]. In Nigeria, positive health and safety information-seeking behaviour was found in ASM [23]. In addition, training on health and safety was associated with best health and safety practices [22] in Ghana. Thus, despite unsafe actions associated with human error, Reason (2017) has defined humans as heroes who can adapt to situations to promote safety [35]. Safety culture is therefore described as a behavioural approach [6].

Implementation (e.g., ASM regulations, financing of health and safety in ASM, training on health and safety practices in ASM) and follow-up of health and safety practices could be promoted through a multi-stakeholder approach (Figure 1b) among the miner(s), mine owners, ASM associations, the Ministry of Mines and Mine Development, financial institutions, and other stakeholders including Environmental Management Agency (EMA). A 'cross-scale' and 'cross-level' approach has been proposed to mitigate challenges in ASGM [36]. Hence, the need to integrate government agencies, local government representatives, community leaders, LSM, and public health programs in ASM risk management [6,11,21]. Furthermore, the literature has found LSM-ASM collaboration (Figure 1b) as one way to introduce health and safety in ASM [6,21,26]. The International Labour Organisation(ILO) (1999) and Smith et al. (2016) identified the need for a public and community health approach (Figure 1b) to mitigate health issues in ASM [6,11]. Therefore, a multi-stakeholder approach is suggested to reduce health and safety risks in ASGM (Figure 1b). In addition, poor sanitation and hygiene, malaria, tuberculosis, sexually transmitted diseases, and malnutrition are prevalent in ASM [6,7,9–11] highlighting the relevance of public and community health interventions [6,11] (Figure 1b), including awareness raising, counselling, screening, and outreaches to ASM communities.

ASGM is associated with hazardous working conditions, high exposure to dust, chemicals (mercury and cyanide), noise, vibration, poor ventilation, over-exertion, confined workplaces, inadequate equipment, and compromised safety practices, resulting in fatalities, respiratory diseases, and poor health [3,6,9,24,26]. The Minamata Convention on Mercury in ASGM, therefore, focuses on reducing and eliminating mercury use through initiatives such as the Planet Gold interventions [37]. In addition, international Non-Governmental Organisations (NGOs) have extended due diligence to ASM through programs such as the CRAFT Code [38]. However, a review of health and safety in ASGM reveals a lack of comprehensive health and safety management in ASGM [14], and the literature has therefore recognised the need for health and safety risk mitigation and prevention measures in ASM [11,13,21,24]. Furthermore, accidents and fatalities in ASM [39] usually assign the sector with blame rather than attempting to understand the causal factors or implementing mitigation measures [5]. Therefore, preventive health and safety programs in mining must be a global priority [40]. Yet, there is little research on risk mitigation in ASM. Thus, this study explores health and safety risk mitigation in ASGM to inform relevant interventions. The objectives include (1) exploring the causal factors for accidents and poor health in ASGM and (2) identifying an approach to risk mitigation for health and safety in ASGM in Zimbabwe.

2. Materials and Methods

Data were collected in 2017 and 2020 in Kadoma and Shurugwi in Mashonaland West and Midlands Provinces, which are characterised by high ASGM activity [41]. Smith et al. (2016) proposed the application of quantitative and qualitative methods to understand the nature of health and safety risks in ASM [11]. Hence, a qualitative research design was used to answer questions about the "what", "how", or "why" of incidents [42] to explore the factors and attitudes contributing to health and safety in ASGM in Zimbabwe. Data were also supplemented with data from focus group discussions (FGDs) and in-depth interviews (IDIs) from a previous study conducted in 2017 [10].

2.1. Focus Group Discussions 2020 Survey

Focus group discussions (FGDs) explored the factors contributing to health and safety challenges in ASGM in Zimbabwe. The focus group guide addressed issues such as accidents and injuries, health and safety measures, and practices (Appendix A). The focus group guide was developed, piloted at a site in Kadoma, and translated into Ndebele and Shona. The Medical Research Council of Zimbabwe (MRCZ) approved the research protocol and focus group guide. The FGDs were conducted at ASGM sites during working hours as part of a cross-sectional survey on health and safety in ASGM in Zimbabwe. The target population was artisanal and small-scale gold miners working in Kadoma and Shurugwi.

The 2020 survey targeted mining areas in Kadoma and Shurugwi where rudimentary and more mechanised mining methods were used [7]. A simple stratified random sample was then drawn by reshuffling the names of identified practising rudimentary and more mechanised mining methods [7]. Thirty-four sites were visited in Patchway, Battlefields, Sanyati, Mayflower, Brompton, and Mudzengi in Kadoma, and Wonderer and Chachacha in Shurugwi in the 2020 survey [8]. Participants for focus group discussions were then selected randomly from the visited sites. Consenting adults aged 18 years and older who had been engaged in ASGM for at least six months were included. Drunk, disinterested, and uncooperative respondents were excluded. The FGDs were conducted during the rainy season in November 2020 at mining sites at a reasonable distance from the sources of noise and destruction. FGDs from the 2020 survey consisted of 5–16 participants and were conducted in the participants' language, Shona; all participants had Shona as their first language (there were no Ndebele speaking participants among the study sample). The sessions were recorded using a Samsung digital voice recorder, transcribed in MS Word in Shona, and translated to English and reviewed by the translator.

2.2. Data from Focus Group Discussions and In-Depth Interviews 2017 Survey

Transcripts of IDIs and FGDs, and summary notes of IDIs from another study conducted by the University Hospital of LMU Munich, Germany, in October 2017 [10], were used to supplement the findings. Snowball sampling was used in 2017 due to difficulties in accessing miners. Specifically: local partners were contacted first, and initial participants were approached for different sites. This process was continued. Eight sites were visited in Pingo, Patchway, and Lasgos [10]. FGDs focused on accidents and injuries, health and safety challenges, and existing practices. The topics for the IDIs targeted existing health and safety, the use of PPE, and related difficulties (Appendix B). The FGDs and IDIs targeted miners working in ASGM in Kadoma. The IDIs were conducted during working hours on mining sites and were selectively recorded at locations where the noise level was tolerable.

All study participants had Shona as their first language. The participants' preferred language, English or Shona, was used for the IDIs. The principal researcher was a foreigner, and the participants' preference for English facilitated direct interaction between the principal researcher and the study population. The FGD with the mine owners was conducted in an office in the town of Kadoma. The FGDs with miners took place on-site, at a reasonable distance from the sources of noise and destruction. The primary language of the participants (Shona) was used for the FGDs; FGDs were recorded. Summary notes were taken in Shona for the IDIs conducted by the research assistant who had Shona as a first language. IDIs which were conducted by the principal researcher in English were recorded. The FGDs and selected IDIs were transcribed in MS Word in Shona (FGDs) and

English (IDIs). Finally, the transcripts and summary notes in Shona were translated into English and reviewed by a translator.

2.3. Data Analysis

The multi-causal analysis and multi-stakeholder risk mitigation framework (Figure 1) was used for data analysis. Transcripts of IDIs, FGDs, and summaries of the qualitative interviews were printed out and reviewed to familiarise the data. The data sets were imported into NVivo. Initial content analysis was performed through auto-coding in NVivo to visualise and understand the data. Coding was done using MS Word [43] with reference to the printouts reviewed, as access to qualitative research software was limited. NVivo was accessible during a short training session while the principal researcher for the 2020 survey had to perform the data analysis as part of the study. Emerging themes were identified. An initial classification of codes was created for recurring themes. Sub-coding was done according to the emerging sub-themes. Parent, child, and child–child nodes were identified and collated according to the conceptual framework (Figure 1). Mind mapping was done to visualise the codes compiled, as presented below. The frequencies of similar codes were aggregated as shown below. The data were quantified, and percentages were calculated in Microsoft Excel and analysed using descriptive statistics. The findings were presented in tables, graphs, charts, and direct quotations.

2.4. Ethical Approval

This work was approved by the University of Munich (LMU) Ethics Committee (Project 20-068) and the Medical Research Council of Zimbabwe (MRCZ/A/2603). Consent was sought from local authorities, mine owners, and all participants. Participation was voluntary and the informed consent form was signed before data collection in 2020 and 2017. The survey conducted in Kadoma in 2017 in the dry season was approved by MRCZ (MRCZ/B/1425) [10] and the University of Munich (LMU) Ethics Committee (17-665) [10].

3. Results

Three FGDs were conducted in 2020 with male miners (16 miners 45 min), female miners (5 miners, 21 min) and women who were living in a mining compound (15 women, 60 min). The focus group discussions were conducted on mining sites that were practising more mechanised mining methods in Shurugwi. Focus group discussions with men and women were conducted on the mining sites during working hours. Focus group discussions with women living in a mining compound were conducted on the mining compound at an appointed day and time. FGD were conducted on registered sites which were owned by individuals.

The findings were supplemented with existing data from three FGDs and 84 IDIs from the 2017 survey. Focus group discussions with miners were conducted on a registered mining site owned by an individual and a processing centre owned by an ASM mining company. The focus group discussion at the processing centre consisted of 17 miners (16 men and 1 woman) and was conducted for 58 min. The focus group discussion which was conducted on a mining site had 31 participants (men), participants were split into two groups of 15 (30 min) and 16 (28 min). Focus group discussions with mine owners (18 men, 65 min) were conducted in an office in Kadoma. Participants in the IDIs were aged between 19–70 years. IDIs had a response rate of 98%. Of the 84 IDI participants, 15 (18%) were women, and 69 (82%) were men.

Six transcripts of FGDs from the 2017 and 2020 surveys and seven IDIs transcripts from the 2017 survey were analysed, along with summary notes from 77 IDIs using the multi-causal analysis and risk mitigation framework, Figure 1. During the same study in the 2020 survey, the reported prevalence of health and safety problems was 45% (178) [7], accidents and injuries were reported as 35% (140) and 26% (103), respectively [8].

3.1. Multi-Causal Analysis of Risk Factors Contributing to Health and Safety among Artisanal and Small-Scale Gold Miners in Kadoma and Shurugwi, Zimbabwe, in 2017 and 2020

The identified causal factors included immediate causes, workplace factors ASGM-related factors, and contextual factors with no clear-cut distinction beteen the majority of the factors. Workplace factors such as unsafe shafts and incompetent people were found. The reported factors contributing to health and safety in ASGM are illustrated in Figure 2, below.

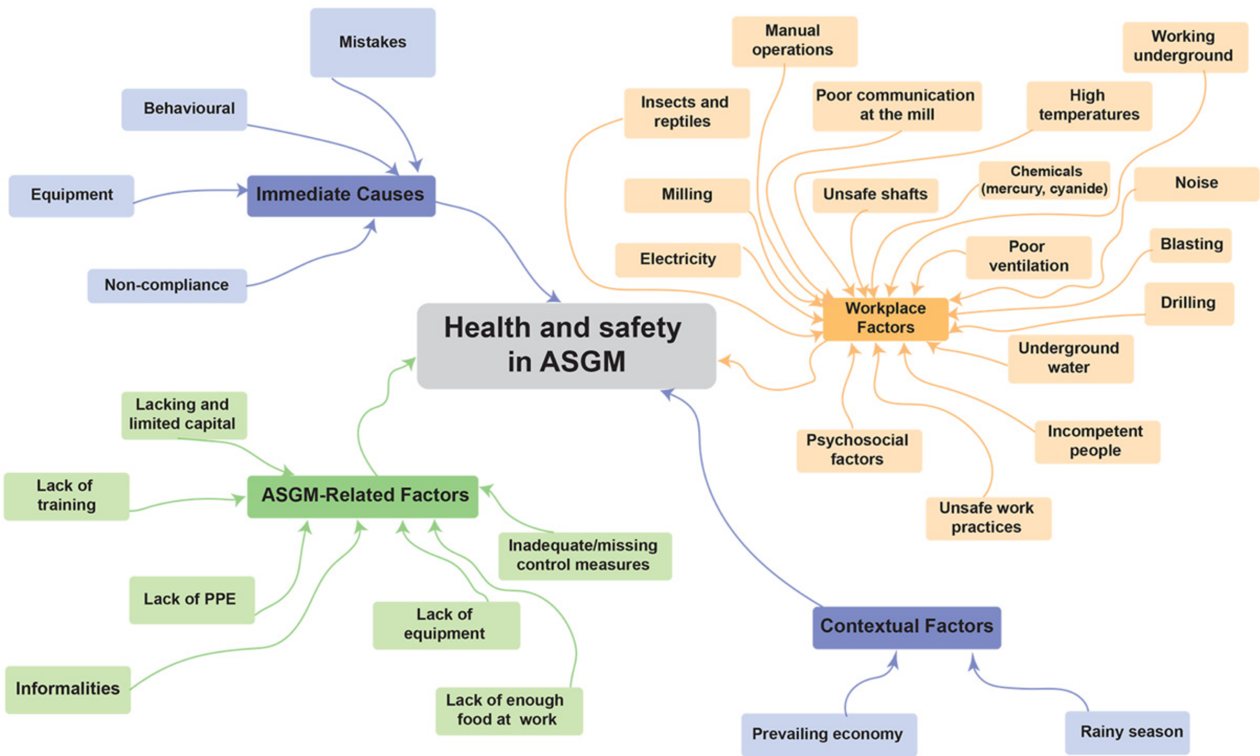

Figure 2. Mind map: multi-causal analysis of reported risk factors contributing to health and safety in ASGM in Kadoma and Shurugwi in Zimbabwe in 2017 and 2020.

Underlying informal practices in ASGM influenced the workplace and immediate causes. For example, inherent informal practices and lack of training in the sector which in turn influenced unsafe work practices such as mining of support pillars.

Human behaviour included a negative perception of PPE use. In addition, non-compliance with known safety standards was widespread, as further presented below, Table 1; see Table S1 for more detail.

The rainy season was associated with the weakening of the shaft walls and shaft collapses due to wet ground conditions which confirms findings from the 2020 survey [7]. During the same survey (2020), rising unemployment and the declining economy, exacerbated by COVID-19, made ASGM a promising source of employment [7].

Findings based on the voices and direct experiences of miners are presented below.

Table 1. Multi-causal analysis of factors reported by artisanal and small-scale gold miners as posing safety and health risks in Kadoma and Shurugwi in Zimbabwe in 2017 and 2020. Numbers in parentheses illustrate the total recurrences of identified themes and sub-themes in the qualitative data. See Table S1 for more details.

Immediate Causes (78 Total Recurrences in Qualitative Data)			
Harmful Behaviour (58)	Negative perceptions (35) Unsafe sexual behaviour (1)	Preference for mercury use (8) Workplace violence (9)	Alcohol abuse (5)
Non-compliance (16) Mistakes (1) Equipment (3)	Non-compliance, PPE (9) 2* No development (2) Forgetting to wear gloves (1)	1* Compromised waiting (3) Mining survival tactics (1)	Mining of pillars (1)
Workplace Factors (246 Total Recurrences in Qualitative Data)			
3* Chemicals (103)	Chemical dust (34) Cyanide (8)	Mercury (29) Acid and caustic soda (4)	Toxic gases (25)
4* Unsafe shafts (34)	Rock falls (16) Slipping (1)	Collapsing mines (8)	Sub-standard shafts (3)
Other workplace factors (109)	5* High temperatures (10) Confined workplaces (3) Blasting (4) Incompetent people (4) Noise (11)	Milling (8) Poor sanitation (9) Poor ventilation (3) Psychosocial factors (11) Manual operations (2) Electricity (1)	Biological hazards (8) Underground water (5) Poor communication (2) Drilling (4) Working Underground (2) Unsafe practices (22)
ASGM-Related Factors (146 Total Recurrences in Qualitative Data)			
Inconsistent income (7) Subsistence mining (2) Workplace starvation (8)	Lack of PPE (37) Limited capital (5) Compromised controls (37)	Weak winch rope (2) Lack of security (1) Informal practices (20)	Lack of equipment (3) Lack of training (24)
Contextual Factors (3 Total Recurrences in Qualitative Data)			
	Rainy season (2)	Prevailing economy (1)	

1* Compromised recommended waiting period after blasting; 2* Neglecting the initial stage of mine development; 3* Chemicals (n = 3) Total for all chemicals (n = 103); 4* Unsafe shafts (n = 6) Total for unsafe shafts (n = 34); 5* High temperatures underground shafts and summer time.

3.1.1. Workplace Risk Factors

The themes that recurred as workplace risk factors included environmental pollution, unsafe work practices, incompetent people, and psychosocial factors. For example, unsafe practices included overwork, lack of safety talks and checks, overcrowded shafts, and uncontrolled blasting. Psychosocial risk factors included workplace violence, stress, and family absence (Figure 2 and Table 1).

Environmental Chemical Pollution

Exposure to chemicals was the most common environmental hazard in the workplace. Miners were exposed to mercury, chemical dust, and toxic gases from blasting (Table 1). The retort with an enclosed protective system for gold-mercury amalgam burning had been introduced to avoid open amalgam burning and reduce exposure to mercury gas. However, there was low response uptake of the retort and open amalgam burning was common, Figure 3b. Cyanide leaching from mercury-containing tailings was practised, as shown in Figure 3a below.

(a) (b) (c)

Figure 3. Chemical pollution in the workplace: (**a**) chemical contamination: cyanide leaching from mercury-containing tailings and dust from tailings, Shurugwi 2020; (**b**) open amalgam burning, Kadoma 2020; (**c**) fuel emissions from fuel-powered machinery and dust from mercury-containing tailings, Shurugwi 2020.

Environmental mercury and cyanide pollution was common, Figure 3a,b. In addition, there was a site owned by a mining company that had an upgraded treatment facility for cyanide leaching from mercury-containing tailings (presented below), which is associated with increased releases of complex mercury and cyanide chemicals into the environment, with potential adverse impacts on the health of miners, their families, and ASGM communities. Open amalgam burning was practised (Figure 3b), and the use of mercury was preferred as shown below. Hammer mills were common in Shurugwi; it was typical for a processing centre to operate more than five diesel-powered hammer mills at the same time, which was associated with fuel emissions, noise, cramped working spaces, and dust from mercury-containing tailings (especially in the dry season), Figure 3c. Dust exposure was a predominant workplace risk factor (especially in the dry season) from dry drilling, milling, and tailings [7]. Furthermore, there was no safe management of chemicals as shown below. In 2020, during the same study, hazard identification and risk assessment identified numerous hazards in ASGM including chemicals, mine-contaminated drinking water, chemical contamination of farmland, and poor management of mine waste, and silica dust, which required attention [7]. Cigarette smoking at mining sites was also widespread during the 2020 survey. In addition, participants confirmed occurrences of tuberculosis (TB) among the miners in ASGM:

> *'When drilling, there is a need to cover the mouth and nose because dust from drilling can affect health, like the lungs and TB.'* (FGD, men, Kadoma)

Miners were also aware of free TB treatment:

> *'With TB, you do not pay … but … You pay until diagnosed TB positive; then, you will be declared a government property (for free TB treatment).'* (FGD, mine owners, Kadoma)

However, the miners could not afford the initial consultation and TB tests required for free TB treatment, hence the need for community and public health interventions on TB screening.

Unsafe Shafts

Unsafe shafts led to rock falls and collapsing mines. High temperatures, poor ventilation, and toxic gases could be associated with confined workplaces and the lack of ventilation routes. Accumulation of gases from blasting was typical in underground shafts. As discussed below, one participant pointed out the need for gas-testing equipment to monitor gases in underground shafts. In addition, miners did not adhere to the recommended waiting period for re-entry after blasting.

Noise

High noise levels were typical in milling centres, especially stamp mills. Noise levels were not controlled. As discussed below, one FGD participant was concerned about the lack of equipment to monitor noise levels (Table S1). Despite the high noise levels, especially at sites with multiple stamp mills operating simultaneously, hearing protection was not standard, as presented further below. Accidents and injuries in the milling centres (especially at stamp mills as presented below) were also associated with poor communication between operators, which was influenced by excessive noise levels [7]; hearing problems were reported during the same study in the 2020 survey [7].

Violence

Workplace violence was reported:

> *'There are issues like failing to understand each other because of money. Typically, when there is money, there is fighting, violence, attacks, and stabbing.'* (FGD, mine owners, Kadoma)

Conflicts and misunderstandings about money often resulted in violence. There were also reports of violent attacks by perpetrators nicknamed '*maShurugwi*' (people from Shurugwi). In addition, violence was associated with disputes over unregistered claims at the discovery of rich deposits. One participant expressed that the lack of security guards and site registers exposed workers to invasions and violence as presented below.

Stress

Stress was reported as shown in Table S1. Stress was also associated with being away from families. Miners could not visit their families regularly because of the uncertainty of their income:

> *'Challenges with visiting our families because of erratic salary.'* (FGD with a men, Shurugwi)

Miners' wages were unstable. Miners worked on a share basis, involving percentage sharing after profitable production, which was rare. In addition, for the salaried miners (monthly salary), consistent earnings were scarce because of unprofitable production as well as unfair employers, as presented below.

Lack of Training

Incompetence and lack of experience were prevalent among blasters and electricians (Tables 1 and S1). One participant commented that inexperienced blasting was associated with injury as was confirmed in the 2020 survey during the same study [7].

3.1.2. ASGM Sector-Related Factors

ASGM related factors (Table 1) included lack of capital, lack of PPE, lack of training, insufficient control measures, and informal practices. In addition, the lack of money could be associated with the lack of PPE and the inability to invest in effective control measures (Table 1).

Lack of Finance

Miners reported having no financial support. As a result, individual miners could not fund health and safety equipment.

> *'It is difficult to follow safety rules because some things require you to put money down when looking for cash. So, you can say "chero zvazvaita" ("whatever happens") to get money to take care of the family instead of working for health and safety.'* (FGD, male miners, Shurugwi)

Moreover, PPE was not affordable, for the miners engaged in subsistence mining:

> *'[PPE] is not expensive. The only challenge is that rent is also needed.'* (FGD, with men, Kadoma)

Most miners had low incomes and family obligations. In 2020, 229 (61.2%) of the miners worked based on sharing a percentage of profits. Since returns were not always profitable, earnings were low and irregular [7]. One participant commented that a work suit could wear before the next payment.

Some mine owners who participated in the FGD in Kadoma were aware of safety measures. These included standard shaft support of the mine, the sinking of standard shafts with adequate working space, the provision of two shaft entrances for better ventilation, and an escape route for emergencies.

> *'Good ventilation is expensive to achieve. We do collective bargaining. People cannot work to develop the mine; they want to mine where there is gold. If shafts were to be adequately sunk, two ventilation shafts would be needed for good ventilation. We use . . . . survival tactics without proper mining, which causes unsafe working conditions.'* (FGD, Kadoma mine owners)

Miners could not introduce effective control measures, such as standardised mine development.

One mine owner indicated a willingness to comply with health and safety standards:

> *'[The] willingness is there; what is needed is money.'* (FGD with mine owners, Kadoma)

Despite the desire to comply with safety standards, miners had no capacity to pay for safety.

Lack of On-Site Security Guards

Most sites lacked security personnel, and miners expressed that the lack of on-site security exposed workers to violence, as noted above.

> *'Mines involving more extensive operations need security and a registry of the names of people working in a specific shaft because we have many issues. When there is no registry, perpetrators can get into a shaft; there are cases of looting that can involve injuries to the people working in the shaft. "MaShurugwi" (people who come from Shurugwi) perpetrators invade because there is no security to protect the workers.'* (FGD with men, Shurugwi)

Miners were at risk of assault, attack, and injury without strong on-site security. At the same time, it was expensive for mine owners to pay for security services:

> *'The other challenge is security; security must prevent raiding, but security is costly. I have just received a bill for 2350 USD, which has been accumulating.'* (FGD, male mine owners, Kadoma)

Security guards were essential to preventing violence and raids; however, miners were limited in their capacity to pay for professional security services.

Violence was also associated with informal mining activities when a mining licence was granted for unregistered claims occupied by informal miners as presented above. The registration process was expensive for informal miners.

Compromised and Missing Control Measures

Compromised and missing control measures occurred 37 times in the qualitative data (Table S1), representing 25% of the ASM related factors. During the same research period, PPE was the most frequently cited control measure, and use of PPE was associated with gaps. Furthermore, effective engineering control measures were absent, such as safe mine support, wet blasting, and acceptable noise levels [7,8].

Informal Practices

These included gold rushes, lack of ASGM-specific regulations, lack of enforcement of existing regulations, and unregistered miners (Tables 1 and S1).

Gold rushes were associated with high migration, overcrowded shafts, uncontrolled blasting, weak walls, and rock falls:

> '[There were] *too many people in an old shaft, 5000 or more people working with no control, uncontrolled blasting, weak points, and rockfalls 48 or more levels.'* (migrating miner, male, 32 years ID1, Kadoma,2017)

The migrating miner stated at he did not have time to use PPE during gold rushes.

The reported informal practices in the sector led to violations of known practices such as the use of PPE and mercury use, the observance of post-blasting waiting periods, and the continuous unsafe use of mercury, as presented below.

Lack of Accident Investigation, Accident Reporting, and Access to Health Care

Accident investigations were conducted externally in the event of a fatal accident. However, mine owners stated that that mine collapses were associated with fear of the police:

> '[If a] *mine collapses, it is difficult to get help, and colleagues can run away because of the police. If the case is reported, the police will ask for a statement issue to be reported so the fellow miners keep quiet. The incident may go unreported, yet someone could be rescued and saved.'* (FGD, mine owners, 2017, Kadoma)

As a result, accidents were rarely reported, as confirmed in the 2020 survey [7,8], necessitating cooperation with rescue services.

In the same survey, access to health care was described as limited, and there was no access to health insurance nor social security coverage for ASGM [7,10].

3.1.3. Immediate Causal Risk Factors

The factors that were consistently cited as directly contributing to accidents and injuries (Table S1) were behavioural (58), non-compliance (violations of known standards) (16), and equipment (3), as illustrated below (Figure 4).

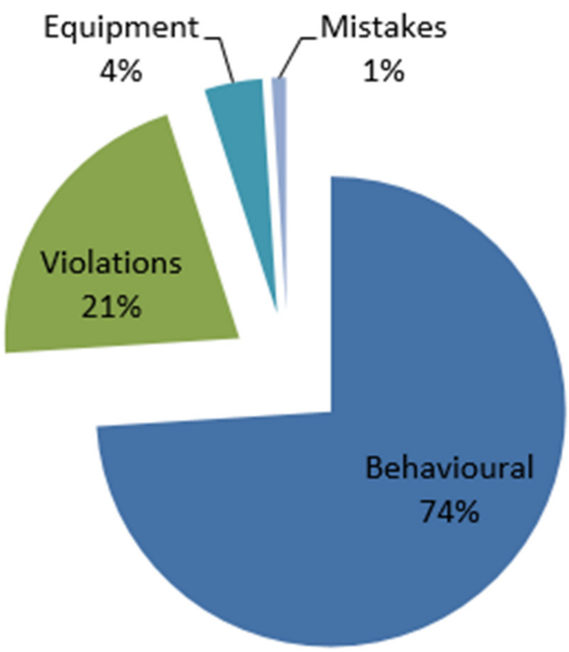

Figure 4. Distribution of immediate causal factors among artisanal and small-scale gold miners in Kadoma and Shurugwi in Zimbabwe in 2017 and 2020.

Violations consisted of non-compliance to known best practces Table 1. At the same time non-compliance and behavioural factors were dorminant as presented below.

Behavioural Risk Factors

The most significant behavioural factor was the negative perception of PPE and mercury use (Table 1). Some miners even believed that working without PPE was necessary:

> *'The issue is when hitting with the hammer, you hit hard and sweat, and it's preferred for one to be free without PPE because one will be working hard.'* (FGD, male miners, Kadoma, 2017)

This was confirmed by informal conversations, which revealed a preference to work in old and torn clothes known as "*pendenge*". In addition, compliance with PPE use was found to be difficult for informal miners employed by registered miners and ASM mining companies which were providing PPE. Mine owners in FGD in Kadoma reported experiences of miners entering shafts wearing PPE and then removing it while working underground. The provision of PPE was also associated with the high turnover of informal miners, as informal miners tended to move from site to site after receiving PPE. Moreover, the Chinese-manufactured respirator was considered uncomfortable, while the comfortable respirator was said to be expensive. At the same time, non-compliance with PPE use while working underground was also associated with the cramped working space and high temperatures underground (Table 1 and Table S1), as explained below.

Alcohol and Sexual Behaviour

Alcohol abuse in the workplace and sexual indulgence were among the immediate causes. Focus group discussions revealed concerns about the lack of free condom distribution in ASGM communities,

> *'STIs (sexually transmitted infections) like syphilis. There are no free condoms. Sex is without protection.'* (FGD, men, Shurugwi)

Sex was unprotected, and sexually transmitted infections were common. In addition, miners were away from their families, and it was not easy for miners to visit their families, as explained above.

It was also reported that the spread of HIV was typical when miners had money:

> *'Then getting too much money harms people when they get over-excited and get involved in sexual indulgence .... we have lost colleagues to HIV.'* (FGD with mine owners, Kadoma)

Therefore, community and public health interventions are needed in ASGM communities.

Non-Compliance and Violations

There were violations of the use of PPE and existing regulations, including standard shaft support, mine ventilation, escape routes, winch rope change, post-blast waiting time interference, and mining pillars, as was confirmed during the same study [8].

One participant confirmed informal practices that resulted in a violation of mining standards:

> '[When] *working underground, I open a small hole ... with poor ventilation, and I use explosives in that tiny hole. Despite the fumes from the blasting, I immediately get into the small hole after blasting to get money faster to pay rent at home.'* (FGD, male miners, Kadoma)

The miners did not comply with the mining regulations on shaft sinking and post-blasting waiting period as confirmed in the 2020 survey [7].

The violations of mining standards were related to the cost of standard shafts and the scarcity of trees for recommended timbering:

> *'Shafts must be made safe. People must use cement for shattering, but the prices are high . . . ., and people may decide to use timber. Trees for timbering are becoming fewer and fewer in the forests. Some types of trees that used to be there in the past cannot be found in the woods or are now in distant forests, and it is costly to get them. Most people, therefore, work without timbering, resulting in collapsing mines.'* (FGD, mine owners, Kadoma)

In addition, the FGDs revealed that non-compliance with PPE use was due to the limited working space and poor ventilation underground:

> *'Most of the shafts have poor ventilation, below the expected standards. As a result, some miners say they cannot wear protective clothing; the problem is limited working space and poor ventilation. In the standard shafts, people can work with protective clothing.'* (FGD, mine owners, Kadoma)

The discomfort of wearing PPE was also due to the limited working space underground.

Furthermore, some miners knowledgeable of the recommended post-blasting waiting period did not comply:

> *' . . . our job is risky, even with blasting, you must get in after a specific time after blasting, but with us, our work is "chikorokoza" "informal", you get in just after blasting when the fumes are still there.'* (FGD, male miners, Kadoma)

Although there were individual miners who were informed about the post-blasting waiting period, there was no compliance. There was also the case of a site operated by a Chinese company where workers were forced to re-enter shortly after blasting. The miners at the said site worked on a wage basis and were not paid for months despite being in production. Further discussions with the miners revealed that there was no grievance mechanism. Therefore, the only option for the informal miners was to migrate to a different site without compensation, which was quite common.

Equipment Use

Causal risk factors included using equipment without safeguards, no use of PPE, increased mercury and cyanide pollution, dust from dry crushing and dry milling (hammer mills), and unsafe electricity, as shown below.

As shown above (Figure 5a–f), some registered mining companies sought high returns by switching to ASM mechanised equipment. However, informal practices, individual behaviours, and lack of training in equipment operation, management, and maintenance could contribute to health and safety problems, as demonstrated by the lack of safety precautions (Figure 5d), failure to follow standard operating procedures for personal protection (Figure 5a–d), and unsafe management of electricity (Figure 5f). For example, in the 2017 survey one miner operating a ball mill without gloves confirmed that he had forgotten to wear gloves [7] while another miner working in contact with cyanide stated a tendency of forgetting to wear the gloves [10]. Nevertheless, the miners found working with gloves uncomfortable. As can be seen in Figure 5, some individuals and mining companies had mechanised equipment without control measures. Technological progress was also associated with a need for industrial power, and unsafe electrical wires (Figure 5f) posed a risk. At one site, the mining camp had unburied electrical lines and children were playing on the compound.

Figure 5. Causal risk factors associated with equipment used by artisanal and small-scale gold miners in Kadoma and Shurugwi in Zimbabwe in 2020: (**a**) hazardous noise exposure at a site with six stamp mills operating simultaneously with no technical measures to reduce noise and with no hearing protection; (**b**) mining site with improved equipment for underground mining, headgear is used instead of a winch to transport people and material, workers under the headgear do not wear PPE; (**c**) headgear operated without safety shoes, the operator wears open-toed shoes while operating the headgear with bare hands and without gloves; (**d**) hammer mill operator in contact with moving parts of the hammer with no safeguards, the operator wears no gloves; (**e**) mechanised ASGM processing plant capable of increasing the throughput of cyanide leaching from mercury-containing tailings at a mine site close to a mine compound, without environmental monitoring of chemical pollution; (**f**) unenclosed outdoor electricity junction box.

3.1.4. Contextual Risk Factors

The rainy season and the general economy were the identified contextual factors in Table 1. The 2020 survey was conducted during the COVID-19 pandemic, which was characterised by inflation and rising unemployment. More than 50% of the respondents were between 18 and 35 years old [7]. Overworking (Tables 1 and S1) was one of the workplace factors that could be associated with long working hours and night shifts. In the 2020 survey, long working hours, and an age range between 18–35 years were associated with increased accidents and injuries [7]. Hence, the need to understanding contextual risk factors in risk mitigation in ASGM in Zimbabwe.

3.2. Health and Safety Risk Mitigation Practices Reported from Focus Group Discussions (FGDs) and In-Depth Interviews (IDIs) in Kadoma and Zimbabwe in 2017

Table 2 presents the potential health and safety mitigation measures indicated by miners.

Table 2. Emerging themes on health and safety risk mitigation measures reported by artisanal and small-scale gold miners in Kadoma in Zimbabwe in 2017.

Theme	Examples of Quotes from Focus Group Discussions (FGD)
Formalisation and financing	*'There should be mine regulations for PPE to be checked at entry … and underground. Safety management should be available to monitor the use of PPE because if not monitored, it's still a cost when a worker gets injured.'* (FGD, mine owners, Kadoma, 2017) *'Ventilation needs capital, mine development needs capital. Capital should be made available to miners after getting the license.'* (FGD, mine owners, Kadoma, 2017)

Table 2. *Cont.*

Theme	Examples of Quotes from Focus Group Discussions (FGD)
Organise and plan	*'We do mining. Before mining, the leader should go down to check on safety as well as on the timbering. If not safe, safety measures are taken, after which the miners can go down and work.'* (Female miner, FGD male and female miners, Kadoma, 2017) *'That can be a belief* (of not using PPE) *among people* [ASG, miners], *but there should be order* (workplace organisation) *when people are at work. Anything can happen, but one should go down organised. People must not have an attitude to say, whatever happens, happens. If you do "chiite-ite" ["working haphazardly"], it's risky, any accident can happen, and you get injured. We need to wear PPE, and we need a . . . . cloth, and we must wear it. Dust will not stop affecting you because you ..call.. yourself "Munija" [informal miner]. Dust will still get into your system, and over time you will get affected* (getting affected over time). *So, it's important to work with protection. It's important to teach each other to protect, not to destroy. Protection is important.'* (FGD, male miners, Kadoma, 2017) *'In mining there must be avenues to get prompt results, like after taking water to the laboratory for analysis. Many questions and many charges will make people look for survival methods without taking the water for testing* (testing drinking water for chemical contamination e.g., cyanide, acids, mercury, caustic soda). *People can look for shortcuts that can result in harmful effects in the future.'* (FGD, mine owners, Kadoma)
Behaviour	*'The issue is* (that) *when hitting with the hammer, you hit hard and sweat, and it's preferred for one to be free without PPE because one will be working hard.' (FGD, male miners, Kadoma, 2017)* *'When it was introduced* (the retort), *we did not take it up. But it's* (the retort) *a good thing it recycles mercury . . . . The problem is we are used to our survival technics.'* (FGD, mine owners, Kadoma) *'We will get behind time* (if we use the retort) *because our job in artisanal mining is seasonal; when rain begins we focus more on farming . . . . If the retort is slow we will put it aside, if the retort is time efficient then we will use it.'* (FGD, mine owners, Kadoma) *'You get no gold without mercury.'* (FGD, male and female miners, Kadoma, 2017) *'It depends on how the technology works. We are convinced after seeing how it works. At the moment we are convinced that if we use mercury we extract all the gold.'* (FGD, male and female miners, Kadoma, 2017)
Action and follow-up	*'Every day before starting work, we have talks on the type of PPE one should use. Checking the PPE for snakes and scorpions before wearing PPE. There could be a snake or scorpion hiding in the gumboots; one must therefore check what could be hiding in the gumboots before wearing* (the gumboots).*'* (FGD male and female miners, Kadoma, 2017) *'Here, it's a must to always wear PPE because if you are at work, you are expected to wear PPE until the end of your 8 hours.'* (FGD, male and female miners processing centre, 2017, Kadoma)

While health and safety management practices are rare in ASGM, health and safety management opportunities were identified [8] among ASGM miners in Zimbabwe.

FGDs and IDIs revealed that ASG miners were aware of the need for appropriate ASM policies, funding, and regulation of ASM activities. One of the miners argued that many ASGM miners in Zimbabwe had mining licences. However, the miners had no capacity and no financial or technical support to develop a safe shaft for underground mining:

> *'Ventilation needs capital, mine development needs capital. Capital should be made available to miners after getting the licence.'* (FGD, mine owners, Kadoma, 2017)

The mine owners acknowledged the need for financial support after acquiring the licence.

The mine owners pointed out the need to regulate PPE use to avoid incurring costs related to a worker's injury. However, it was pointed out that formalisation could be resisted in the ASGM sector, if associated with payment of taxes.

Some of the miners interviewed indicated that supervisors and managers were available at their worksites. For example, a woman who owned an operation in Kadoma (2017) expressed that she had a supervisor and a blaster on her site and the supervisor was responsible for safety checks:

> *'We do mining. Before mining, the leader should go down to check on safety as well as on the timbering. If not safe, safety measures are taken, after which the miners can go down and work.'* (FGD, female miner, FGD with male and female miners, Kadoma, 2017)

The FGD above was conducted at the processing site, however, such practices were not observed at the sites visited.

In 2017, two sites operated by different mining companies in Kadoma had health and safety management structures. For example, one of the two sites had an occupational safety and health (OSH) department and a health care unit, which is rare in ASGM. (Unfortunately, the site with an OSH department was closed during the 2020 survey due to the COVID-19 pandemic). In addition, one individual mine owner interviewed off-site in 2017 indicated that he provided and monitored the use of PPE at his site.

The manager from one site operated by a mining company indicated that the company was paying for workers' health care costs including routine medical check-ups.

On the other hand, two registered ASM mining companies (one in Kadoma and one in Shurugwi) that operated processing centres and were working on a percentage sharing basis with informal, artisanal miners, whereby artisanal miners were supplying ore to the processing centres, the registered ASM companies were not providing for the safety needs of the informal miners. While the ASM companies were aware of safety practices, the informal miners in partnership with the ASM companies were not capable of observing any best practices.

The cost of medical check-ups was reported as prohibitive for the average miner, as described below:

> *'Check-ups are good; the problem is money. Consultation fees, x-rays, and blood tests are expensive.'* (FGD mine owners, Kadoma, 2017)

While the miners acknowledged the relevance of routine bio-monitoring in the workplace, medical check-ups were not affordable for the average miners. Hence the need for community and public health interventions involving awareness raising and screening (e.g., HIV, TB, and malaria), and distribution of mosquito nets and condoms. For instance, one respondent from FGD with mine owners indicated that mosquito nets were distributed once in ASGM in Kadoma by the outreach department from Kadoma hospital (mosquito was identified under biological hazards, Table S1). During the same study it was found that Kadoma hospital had limited resources [7].

A preference for the use of mercury was also noted. However, miners indicated that the uptake of mercury-free technology depended on the efficiency of the new technology:

> *'It depends on how the technology works. We are convinced after seeing how it works. At the moment we are convinced that we extract all the gold if we use mercury.'* (FGD, male miners, Kadoma, 2017)

There was a possibility of acceptance of an efficient mercury-free technology comparable to the use of mercury. Furthermore, the mine owners pointed out that mercury was expensive:

> *'If you come up with another technology and demonstrate the gold recovery percentage, we could opt for that because mercury is also a cost to us.'* (FGD, mine owners, Kadoma, 2017)

Behavioural change in the use of mercury could be achieved through efficient alternative strategies.

4. Discussion

The contributors reported as influencing health and safety in ASGM were workplace factors, ASGM-related factors, immediate causes, and contextual factors. Workplace and ASGM-related factors were predominant, as confirmed by previous studies [6,9,10,13,20–22]. Harmful behaviour, workplace violence, unsafe shafts, limited capital, lack of training, equipment, alcohol and drug use, inadequate risk control measures, and informal practices were found as documented in the literature [6–10,24,26]. Multi-causal analysis was applicable to understand causal factors associated with health and safety in ASGM in Zimbabwe. Risk mitigation measures were identified, including formalisation and organisation of health and safety risk reduction. The proposed risk mitigation framework illustrates gaps and weaknesses in each level of risk mitigation [25]. This section discusses inter-linkages between causal factors, health and safety risk factors associated with equipment, and risk mitigation measures characterised by threats.

Immediate causes, workplace factors, ASGM-related factors, and contextual factors were intertwined. As documented in the literature, behavioural factors were among the immediate factors [24,25,33]. However, the causes of accidents and injuries in ASGM sector were interrelated. For example, the practice of sinking unsafe shafts (workplace factor) was a violation of required and known best practices [44] (immediate cause), which was associated with a lack of capital (ASGM-related factor) and exacerbated by the overall economic situation (contextual factor). Furthermore, deforestation had led to a shortage of traditional timber for shaft support. At the same time, previous work has recognised that ASGM is associated with unsafe human behaviour [1,5,6,22,24,26]. Alcohol abuse, preference for the use of mercury over the retort, environmental pollution, and HIV were also reported. However, scholars have confirmed that accidents and poor health associated with individual behaviour in ASM are also due to underlying causes such as lack, ignorance, and the illegal nature of the sector [6,20,23,30,31]. For example, free condoms were not distributed among the ASGM sites visited in Shurugwi, and there were no accepted mercury-free technologies. TB was also reported with limited access to health care. Therefore, mitigation strategies must address behaviours and underlying causal factors [11,18]. Public and community health interventions [6,11], such as awareness-raising and HIV and TB screening and treatment, could also be considered for ASGM.

The use of equipment was one of the immediate factors resulting in accidents and injuries, as documented in the literature [5,8,45]. It was common for miners to use equipment without PPE, confirming previous findings [5,6,10,46]. In addition, blast operators had low levels of competence [6,45,46]. Existing literature shows that blasting and drilling in ASM is dependent on unskilled workers [6,26,47]. Blasting and drilling in sub-standard shafts with poor ventilation and lighting were challenging, as revealed in the literature [48]. It was also typical for blasters to drink traditional beer and take drugs while working, confirming previous studies [10,45,49]. During the 2020 survey, accidents and injuries were more likely to occur at ASGM sites that had transitioned to mechanised ASM equipment which involved underground mining and mechanised processing [8]. At the same time, alcohol and drug use at work is associated with increased injuries and accidents [6,49]. Furthermore, noise pollution from equipment also leads to poor communication and an increased risk of accidents [19]. Increased throughput from mechanised ASM processing plants increases mercury and cyanide complex pollution [36]. While equipment is associated with increased production, technical support on safety precautions and guidance on basic standard operating procedures are essential to mitigate safety risks for mechanised ASGM [45,48]. Yet this mitigation measure is compromised by the level of literacy [6], human behaviour [33], financing, and illegalities intrinsic to the sector [6,29–31].

Formalising the sector by adapting ASM policies, regulating ASM, and funding the sector [5,6,26,29,30] is a prerequisite for effective risk mitigation in ASGM [14,31]. Despite mine owners' willingness to implement preventive safety measures, access to bank loans was limited, especially for miners without collateral [14,30,32]. As a result, miners had limited opportunities to invest in safety and informal practices were common. In addition, as substantiated in the literature, there was a tendency for gold rushes associated with the uncontrolled mining of support pillars, which led to accidents and injuries [6,31]. It was also prohibitively expensive for most miners to hire security guards, and their absence was linked to violence and looting. Violence and evictions were commonplace at unregistered sites when rich gold deposits were discovered [31]. Therefore, adaptive policies, sector regulation, and funding are critical mitigation measures [13,24,30,36]. The formalisation of the sector could lead to the organisation of risk mitigation and transformation of the ASM context, which could motivate behaviour change. For example, formalisation made it easier for ASM workers to join the government social security system and health insurance in Mongolia [50] and Bolivia [6]. However, formalisation also comes with challenges. For instance, ASM regulation without implementation is insufficient, as informality in ASM is also associated with the lack of inspection and enforcement, not lack of regulation [6].

Management is fundamental to risk mitigation [21,27]. The Zimbabwean mining regulation (the same for both LSM and ASM) requires the mine owner to appoint a mine manager [44]. Managers and supervisors were available, especially on registered sites owned by ASM mining companies. Mine owners, sponsors, and individual miners were also identified as responsible for health and safety management in the 2020 survey [8]. For the ASGM sites with management, health and safety risk mitigation could be integrated into the daily management routine. This integration was suggested for ASM companies in Rwanda, where health and safety management in ASM was developed with a focus on the ASM mining companies, and roles were defined according to the existing management system [51]. On the other hand, there was a nexus between registered ASM mining companies and informal artisanal miners [6]. Capable registered ASM companies could be among the stakeholders for implementing health and safety in ASGM in Zimbabwe. In Mongolia, OSH roles and responsibilities were defined among ASM partnerships [32]. However, ASM regulation is still under discussion in Zimbabwe and advocacy for it is ongoing and requires more support from policymakers [29–31]. The CRAFT Code [38] and the Planet Gold Criteria [37] assign site accountability for responsible mining standards to a volunteer, which may not address the accountability gap [21] outside the structured context of the Planet Gold Criteria and the CRAFT Code. Cross-scale and cross-level interventions have therefore been proposed for ASGM [21,36]. This raises the need for a multi-stakeholder approach, including LSM-ASM collaboration [6,21,26]. In Mongolia, formalisation resulted in the institutionalisation of the sector and the distribution of ASM health and safety roles and responsibilities among the relevant ministries and stakeholders [32]. Furthermore, the literature points to the support of large companies, including LSM, in implementing health and safety mitigation measures [6,11,21,36], which could be threatened by weak stakeholder engagement [21].

Vocational training in ASM mining can improve miners' skills while creating the opportunity for economic benefits [5,6,22,26,36], thereby facilitating behaviour change. In Ghana, training on health and safety correlated positively with health and safety practices [22]. In Mongolia, vocational training was conducted in mining districts [32]. Training outreach into ASM communities could also improve participation of marginalised miners [36]. Furthermore, training on accident investigation, risk assessment, and risk mitigation could be incorporated in ongoing interventions such as mercury-free demonstration sites [37]. Jennings (2002) has proposed simple accident reporting conducted by independent agencies focusing on health and safety [52]. Financial institutions interested in the sector could make essential health and safety requirements a prerequisite for financial support to incentivise health and safety mitigation and motivate behavioural change [33]. In addition to training, miners could be encouraged to adhere to good practices in health and safety, for example, facilitating the acquisition of the necessary equipment, for instance access to PPE and shaft support material to promote behaviour change. However, training could be hampered by high staff turnover, the migratory nature of the sector, and low response uptake [6,8]. In the 2020 survey, the migration rate among miners was 28% [8]. In addition, miners expressed low uptake of the retort (after training) and expressed the need for efficient mercury-free technology, which has been documented in the literature [6].

Introducing health and safety measures for ASGM is complex and requires multiple approaches. The proposed health and safety protection layers are characterised by numerous gaps and weaknesses that may open or close as determined by prevailing workplace conditions [25], hence the need to identify and address the underlying causes and turn threats into opportunities for promoting health and safety in ASGM. Moreover, safety is context specific. For example, a site with a single compromised layer of PPE will be vulnerable to adverse health and safety impacts as discussed in our previous articles [7,8], (Figure S1A,B) [8]. In contrast, a registered site that can invest in safety, e.g., a mining ASGM company with an OSH department (Figure S1C,D), can protect the health and safety of its workers [8]. Thus, a multi-stakeholder approach that includes capable ASM companies is needed to protect the health of marginalised informal and disempowered ASGM miners.

Limitations: The findings of this study were self-reported; recall and response biases were possible, and findings should be interpreted with caution. In addition, IDIs were recorded selectively due to high noise levels, especially in the processing centres. The generalisability of the results may therefore be limited. However, the results can serve as a guide and source of information for relevant policies and interventions.

5. Conclusions

This study has uncovered numerous factors contributing to health and safety in ASGM in Zimbabwe, as well as weaknesses in mitigation measures. The intertwined factors contributing to accidents and injuries in ASGM were identified as immediate causes, workplace factors, ASGM-related factors, existing control measures, and contextual factors. Environmental factors in the workplace and illegal practices were dominant. A multi-causal analysis could be applied to identify the immediate and underlying causes to inform risk assessment and accident investigation. Risk mitigation involves successive layers, such as formalisation with a focus on ASM policy, funding and regulation of the sector, organisation of health and safety mitigation, behaviour change, enforcement, and monitoring. Mitigation requires a multi-stakeholder synergy, such as LSM-ASM collaboration, division of roles among relevant sectors, and public and community health interventions. Each mitigation layer has gaps and weaknesses. Hence the need to address threats to health and safety protection in ASGM. In addition, further operational research is needed on health and safety risk mitigation in ASGM. This article proposed health and safety risk reduction in ASGM. However, the informal sector e.g., ASGM is usually marginalised from health and safety prevention initiatives such as zero harm [2]. At the same time the informal sector including, ASGM employs a larger population (exposed to inherent hazards without effective health and safety prevention measures) than the informal sector [1], hence the need for future work and occupational safety and health to consider prevention initiatives such as zero harm for both the formal and informal sectors through addressing barriers to health and safety mitigation in the informal sector (ASGM) at the multi-stakeholder level, as discussed above.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ijerph192114352/s1, Figure S1: Numerous hazards and successive defensive layers: risk management and accident prevention in ASGM in Zimbabwe [8]. Key: high exposure to hazards: A and B: single layer of control measures (e.g., PPE); C: reduced exposure to hazards: double layer control measures (e.g., PPE, administrative controls); comprehensive protection; D: successive layers of control measures (e.g., engineering controls, administrative controls, PPE, and mitigation barriers); Table S1: Multi-causal analysis of reported risk factors contributing to the safety and health of artisanal and small-scale gold miners in Kadoma and Shurugwi in Zimbabwe in 2017 and 2020 [8].

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Informed Consent Statement: Participants signed the informed consent before focus group discussions and in-depth interviews.

Data Availability Statement: Data are available at: Singo, Josephine (2022), "Survey on health and Safety in Artisanal & Small-Scale Gold Mining in Zimbabwe", Mendeley Data, V1, doi:10.17632/v7wd3wjrxm.1. Data from in-depth interviews were collected from a different study and are available per request.

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Appendix A. Focus Group Discussion Guide, 2017

Focus Group Discussion: Men and women ASGM miners

1.

(a) Could you share your experiences with accidents at work?
(b) From your experience how many days have you lost at work because of accidents?
(c) How are you and your families affected by these accidents?
(d) How is your production and earnings affected by such accidents?

In the above context

i. Would you say it is necessary to protect your health and safety?
ii. Which health and safety practices do you have?
iii. How do you burn amalgam (retort, open in the air, at home under closed doors?)
iv. How do you store mercury and the equipment and PPE/clothes you use when burning amalgam?
v. Which measures do you usually follow during blasting?
vi. Which measures do you usually follow during cyanidation?
vii. Which measures do you usually follow when using equipment?
viii. Which measures do you usually follow when developing mining pits and mining?
ix. Where do you get water to drink during working hours?
x. Are you able to use toilets during working hours?
xi. What is the culture on changing the hoist rope?
xii. Which aspects of safety practices do you think needs improvements at your work? Please explain.

2. What is the health and safety issues affecting women in ASGM?
3. How is the health of your family and children affected by your involvement in ASGM?

(a) Have you ever had a disabled child/ child with slow development since you started working in artisanal small scale gold mining?
(b) What are the issues affecting women and children at your workplace?
(c) Is your sexual life affected by your work?

4.

(a) If so, please explain.
(b) If no, please explain.
(c) Who should be responsible for the management of health and safety in the informal sector?

5. Do you think it is possible to extract gold without mercury (mercury free technology) at your work to protect the health of the workers?
6. What are the common perceptions on mercury use and the management of health and safety (mercury use/ mercury free technology, shaft requirements)?
Explosives and blasting requirements (PPE etc.) at your work
7. What do you think are the existing gaps and challenges in managing workplace health and safety at your site (reducing mercury use/ mercury free technology, requirements on shafts, explosives, blasting, fire extinguishers, first aid, PPE)?
8.

(a) What do you think are the factors/issues to address to improve management of OSH in the informal sector e.g., ASGM?
(b) What do you think are the factors/issues to address to improve the compliance to relevant regulations on OSH in the informal sector (ASGM)?

9. What are your suggestions on managing health and safety in artisanal and small-scale gold mining (mercury use/ mercury free technology, shaft requirements, explosives and blasting requirements, PPE etc.?
Would you say the same health and safety regulations in large mines could be applied to artisanal and small-scale mines to improve the safety and health of workers in ASGM?
10

(a) Would you explain how your work was affected by the coronavirus pandemic?
(b) What challenges did you face on the management of your health and safety at work during the coronavirus pandemic?
(c) What is needed for your workplace to be able to recover from the impacts of coronavirus?
(d) What do you suggest being done for OSH management in terms of disaster preparedness and response in ASGM for emerging infectious diseases such as the coronavirus?

11. Where do you see Artisanal Gold Mining in communities in relation to climate change challenges such as drought?

Appendix B

Describe your usual working day	What are your health needs at work	Describe what could be dangerous to your health at your workplace	Which PPE do you have at your workplace	Would you use PPE if you had a choice	What are the challenges with using PPE	What is the impact of mining on your health and your daily life	Possible health interventions

Figure A1. Question guide in-depth interviews (IDIs) (2017).

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5. Appendices

5.1 Health in ASGM

Whilst HIV prevalence was found to be lower (8% n=21) than national figures (11.6%) [(1)], TB was found to be more prevalent in ASGM (7.3% n=28) and higher than national figures (190\100 000) [(2)]. However, this was self-reported data. There is a need for more observational research (involving medical assessment) on illnesses and diseases in ASGM. The reported respiratory symptoms included coughing 13 % (n=53), wheezing without a cold 12 % (n=48), and shortness of breath 11.7% (n=44) (Appendix 1.1). Coughing was reported higher in Kadoma (18.4%; n =38) than in Shurugwi (8.6%; n= 15) (OR = 0.4 [0.2-0.8]; p= 0.007). There was an increased odds of reported coughing among miners in mechanised ASM methods (OR= 5 [1.4-15] p= 0.005*); and underground mining (OR= 2.1 [1.1-4] p= 0.031). Primary smoking, secondary smoking, drug abuse and alcohol use were also found as presented in chapter 4.

5.2 Gendered Workplace Factors Among Women and Children in ASGM

Data from three focus group discussions (2020 survey) revealed gendered health and safety issues as well as potential adverse impacts of ASGM on children. Marital problems were related to family separation. Violence over women as well as commercial sex was reported. Women had limited access to mining licenses, gold, and equipment. Displacement of unregistered women was common. The sector was male dominated because of the hazardous nature of working conditions as well as cultural beliefs against the participation of women in ASGM. Men more vulnerable to accidents and injuries than women. Women primarily occupied the peripheral roles of washing ores (processing) and cooking. Women expressed concern over job insecurity associated with transitioning to processing equipment resulting in substitution and displacement of women. Women had low awareness of exposure to mercury poisoning. Child labour was both a threat and an opportunity to health and education. Findings from FGDs are presented below, Table 5.1

Table 5.1 Gendered Workplace Factors Affecting Women and Children in ASGM

Theme	**Examples of quotations**
Losing wives and husbands	*When a fellow miner gets more money than you, your wife can be attracted and leave you for the fellow miner. Some men get involved with women they meet when mining and stop visiting their families. FGD, Men ASGmers, Shurugwi 2020*

	'Some neighbouring men in ASM get money more frequently and visit their families regularly. …, they get involved with the other miners' wives, who rarely visit home... 'FGD, Men ASGmers, Shurugwi 2020
Visiting families	*'Challenges with visiting our families because of erratic salary. 'FGD, Men ASGmers, Shurugwi 2020*
Women looking for favours	*'Mining with women is difficult. Some women will seek money for favours [sex]. 'FGD, Men ASGmers, Shurugwi 2020* *'That is not for all women; some women come for that [favours]. For us, we come to work. We do not have time to waste, following men. We move from site to site. We are working for our families and can earn more than spending time following men. 'FGD, Women ASGmers, Shurugwi 2020* *'That is possible, but that is a waste of time for some women. Some women always hope to have other men. It depends on the people. Some women are satisfied with what they have. Such things have nothing to do with ASM. ' FGD, Women living with ASGMers in a mining compound (spouses), Shurugwi 2020*
Violence over women	*'There are few women in mines compared to men, which can cause fighting among men, even violence. 'FGD, Men ASGmers, Shurugwi 2020 '*
PPE and mercury	*'Gloves are found. We bought. The problem is that mercury and sand get stuck in the gloves and the nails. The fingers will be exposed to concentrated mercury in the gloves, so we find it better to work with bare hands. We tried it, and we have the gloves. 'FGD, Women ASGmers, Shurugwi* *'There is some mercury which was new and not tested we used it at the other site I once worked. All the women who used that mercury got unexplained weakness and sickness instantly after using that mercury, and we stopped working at that site. 'FGD, Women ASGmers, Shurugwi,2020* *'For us, we do not burn the amalgam…they burn the amalgam while wen watch.' FGD, Women ASGmers, Shurugwi,2020* *'We do not smell the mercury. The mercury affects the person who blows. FGD, Women ASGmers, Shurugwi,2020* *'What we know is we use mercury to get the gold, and the gold that does not need mercury is alluvial. 'FGD, Women ASGmers, Shurugwi,2020*
Accidents & displacement	*We do not get into accidents, but we are left alone with no support. Like now, we do not have jobs. We get good sites when we go to the mountain to search for gold. Once we open and get the gold, you cannot work there. Men in authority come to push us out, work and command us not to come back. ' FGD, Women ASGmers, Shurugwi,2020* *They come, remove the ore, and declare that they do not want to see anyone on the site and apply for the mining certificates. We do not know where to go and report that situation. 'FGD, Women ASGmers, Shurugwi, 2020* *Active mining areas have been taken away, and there is nowhere to mine. 'FGD, Women ASGmers, Shurugwi,2020* *'These are the problems. We open the area, and some people take the site(s) away from us. We open after opening; we are moved out…. we do not have the money to register. We go out to search for gold. When we open, we are chased away. 'FGD, Women ASGmers, Shurugwi,2020* *Women open. After prospecting, they are chased away and cannot work there. 'FGD, Women ASGmers, Shurugwi,2020* *The person who takes over registers brings his security. Then, the security recruits their relatives, and the rest are chased away. 'FGD, Women ASGmers, Shurugwi,2020* *'This is the main issue. Now we are afraid to look for money, and we die of hunger because we have nowhere to work. 'FGD, Women ASGmers, Shurugwi,2020* *'Some women have found good places with gold and have decided not to disclose their area. 'FGD, Women ASGmers, Shurugwi,2020*

Access to equipment	*For us, we do not have mills. When we bring our ore for milling or to the gold buyer, the news of our gold spreads around. We cannot work for two days, the next day, you find the place taken away, and you can be beaten and… slip down the mountain*
Registration	*'So far, we have opened two good places, X and Y, which were taken away from us. 'FGD, Women ASGmers, Shurugwi,2020* *We can organise ourselves, but all those things require money. ...we do not have the money. 'FGD, Women ASGmers, Shurugwi,2020*
Substitution of women's roles by Equipment	*'Does the new technology involve machines? That will disrupt... we can die of poverty. To get the money, we wash…. So, if you bring machines, where do we work? 'FGD, Women ASGmers, Shurugwi,2020* *'The Chinese brought the one that is not good for us, it washes...'*
Access to gold	*The challenge is going underground; we cannot because we are women. FGD, Women ASGmers, Shurugwi,2020* *.... we do alluvial mining; we cannot mine underground. We wait for our children and husbands to work, but now our children and husbands are not allowed when we open. 'FGD, Women ASGmers, Shurugwi,2020* *'The shafts are too deep for women, and women cannot work in shafts. 'FGD, Women ASGmers, Shurugwi,2020* *'We are willing. There are limited places for mining. Some areas no longer have gold. FGD, Women ASGmers, Shurugwi. '2020 FGD, Women ASGmers. 'Shurugwi,2020*
Discrimination	*'Yes. The challenge is that men usually pull women down. We can be despised, yet we have desires and wishes to do something as women, and no one is leading us to get there. FGD, Women living with ASGMers in a mining compound (spouses). 'Shurugwi 2020*
Violence against women	*'In other places, women can be raped when coming from work (ASGM), when walking alone. FGD, Women living with ASGMers in a mining compound (spouses). 'Shurugwi 2020*
Child labour	*'I think it's not good, children will start smoking, and once children get money, they lose focus on going to school. The children will begin focusing on getting more money, getting a few points to buy alcohol and cigarettes. Taking drugs like marijuana is common in ASM. So, the child will change their way of life and be disrupted once they start getting involved in ASGM. Once children start working in ASM, they end up not going to school. FGD, Women living with ASGMers in a mining compound (spouses). 'Shurugwi 2020* *'On respect, the child ends up disrespectful, speaking vulgar words. In ASM, they say vulgar words; nothing is unacceptable. FGD, Women living with ASGMers in a mining compound (spouses). 'Shurugwi 2020* *It depends on the background of the child. If the child is orphaned, without school fees. The child might decide to mine to get money for school fees. So, there are different situations. Such a child may work and go to school rather than stay home without going to school. FGD, Women living with ASGMers in a mining compound (spouses). 'Shurugwi 2020*
Sexual health	*The other thing is tiredness, long working hours, and heavy lifting affecting sex. FGD, Women living with ASGMers in a mining compound (spouses) 'Shurugwi 2020* *'..., when I was working, I used to get so tired that I would get home and sleep because of overworking. FGD, Women living with ASGMers in a mining compound (spouses). 'Shurugwi 2020*
Fatalities with no compensation	*It's common in Wonderer where a mine can collapse and trap 15, 30 men underground, many women and children lose husbands and fathers FGD, Women living with ASGMers in a mining compound (spouses) '. Shurugwi 2020* *'No compensation. ASM is self-employment. FGD, Women living with ASGMers in a mining compound (spouses). 'Shurugwi 2020*

Violence among men was also reported as related to fights over women since there were few women in ASGM. Men ASGMers were also concerned about losing their earnings to women in prostitution in ASGM communities. Risk assessment revealed camps of women in professional sex, targeting men ASGM. During the survey, one woman from that profession was observed drinking beer in the eating area while waiting for 'clients'. Discussions with women ASGMers and women in ASGM compounds revealed that a specific group of women were involved in that trade. Focus group discussions confirmed extra-marital affairs (among men and women), resulting in neglection of official families. Families in ASGM were normally leaving in separate cities or villages. Concurrently, FGDs with men revealed concern over the lack of free condoms in ASGM communities. FGD with mine owners revealed occurrences of STIs and HIV (and HIV-related deaths) in ASGM.

The study revealed unequal opportunities among men and women in ASGM. Women who were digging were mainly in alluvial mining because of limited strength, the hazardous nature of underground mining and cultural beliefs against women's involvement in mining. Women involved in informal alluvial mining occupying the role of exploration (by working) as they were commonly displaced by influential and empowered actors (usually men) who could afford the registration fees at the discovery of rich deposits. While women were also exposed to mercury contamination at the processing centres and were ignorant of the adverse impacts of mercury. For instance, one woman expressed that mercury was affecting the blowers (during amalgam burning) and not women because women were not involved in burning amalgam. However, women were watching the amalgamation process to ensure payment of the agreed remuneration.

Furthermore, women were interested in access to gold; however, the registration fees were reported as high. Informal discussions with a woman miner who was taking a management role revealed a case of a woman managing a registered site owned by a man. The woman (mentioned above) was financing and supervising operations without a management salary, earning a share of 50% of profits. At the same time, the woman had applied for a license and had waited for over a year without receiving a response. The woman expressed that delays in registration were contributing to illegal operations despite the risk of displacement at the discovery of gold.

Child labour was found in risk assessment and was also confirmed in FGDs. Child labour had adverse impacts, including risky behaviours such as drug and alcohol abuse and school dropouts. However, FGDs revealed that orphaned and disadvantaged children who were self-motivated could finance their education through ASGM. Another risk for children was associated with mining activities and amalgam burning in residential areas.

5.3 Hazard identification and risk assessment tool [3]

Item	Hazard identified	Associated risk related to hazard	Probability index	Severity index				Frequency index	Risk score	Risk Category
				I	P	E	C			

I: Injury/disease. **P**: Impact of risk on production. **E**: Impact of risk on the work environment **C**: Associated Cost

Weighted Risk matrix, modified after [3, 4]

Probability Index	Severity Injury/Disease (I)	Severity Production P	Severity Environment E	Severity Cost (C)	Frequency
(5) Very high	**(5)** Fatal	**(5)** No production (Loss of > month)	**(5)** Permanent effects	Very expensive	**(5)** Hazard permanent Present
(4) High	**(4)** Permanent to slight disability	**(4)** Loss of > 1 week to 1 month	**(4)** Long-term> 2 years	Expensive	**(4)** Hazard arises weekly
(3) Moderate	**(3)**> 14 Days recovery	**(3)** Loss of 1 week	**(3)** Medium > 6 months to 2 years	Average	**(3)** Hazard arises monthly
(2) Minor	**(2)** Medical attention full recovery<14 days	**(2)** Loss of 1 day	**(2)** Short-term 1 day to 6 Months	Cheap	**(2)** Hazard arises yearly
(1) Unlikely	**(1)** First aid only	**(1)** Loss of 1 shift	**(1)** Insignificant effect	Very cheap	**(1)** Hazard arises in 5 years

Risk score

$$\boldsymbol{Risk} = \frac{[\boldsymbol{Probability} \times \boldsymbol{Severity}(\boldsymbol{I}+\boldsymbol{P}+\boldsymbol{E}+\boldsymbol{C}) \times \boldsymbol{Frequency}] \times \mathbf{100}}{\mathbf{500}}$$ [3]

Risk Category [3]

Category	*Risk score*	*Action Period*
A	*75-100%*	*Immediate attention required*
B	*60-74%*	*Attention required in 1 week*
C	*45-59%*	*Attention required in 1 month*
D	*30-44%*	*Attention required in 6 months*
E	*15-29%*	*Attention required in 12 months*
F	*1-14%*	*Attention is required as soon as feasible*

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Complete list of my publications

A. Singo J, Isunju JB, Moyo D, Steckling-Muschack N, Bose-O'Reilly S, Mamuse A. Hazards, and control measures among artisanal and small-scale gold miners in Zimbabwe. Annals of Global Health. 2022;88(1). DOI: https://doi. org/10.5334/aogh.3621

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