IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

A Systematic Review On The Effectiveness Of Personal Protective Equipment At The Workplace

[1]Yvonnet Korkor Aklotsoe, [2]Edward Antwi Anim, [3]Ernest Nii Layea Amartey
[1]School of Safety Engineering, China University of Mining and Technology, Xuzhou 221116, China

Abstract: This study explores the effectiveness of Personal Protective Equipment (PPE) in enhancing workplace safety and minimizing occupational hazards in the industrial sector. Despite the critical importance of PPE, data from sand and gravel mining sites reveal inconsistent utilization among workers, leading to a higher incidence of workplace accidents. This study employed a systematic review approach, where data were searched through various databases, including Scopus, PubMed, ScienceDirect, Web of Science, and Google Scholar. The methodological quality assessment of the studies was analysed for quality appraisal. Out of 900 found references, only 9 studies met all the criteria according to the STROBE checklist. The discussion highlights the diversity of PPE types, including advanced innovations such as smart helmets and respirators, which incorporate cutting-edge technologies to monitor environmental conditions, enhance communication, and ensure user safety. For instance, smart helmets, equipped with sensors, augmented reality, and communication systems, significantly enhance head protection and situational awareness. Similarly, respiratory protective equipment, including reusable masks and supplied-air respirators, safeguards workers from hazardous airborne particles. Protective clothing tailored for specific industries mitigates risks from chemical, thermal, and physical hazards. The study underscores the necessity of proper PPE use, training, and innovation to create safer, more sustainable workplaces.

Keywords - PPEs, workplace safety, smart helmets, respiratory protection, protective clothing, occupational hazards.

I. INTRODUCTION

Safety at the workplace is a crucial aspect of industrial operations, ensuring the well-being of workers and smooth work operations. As a critical line of defense, personal protective equipment (PPE) mitigates the dangers of injuries, illnesses, and fatalities caused by occupational hazards at workplaces across various sectors. Additionally, the appropriate use of personal protective equipment (PPE) can reduce injuries and illnesses [1]. A survey, based on United States Occupational Safety and Health Administration (OSHA) forms used to log occupational injuries and illnesses, revealed that the proper application of PPE could have prevented up to 37.6% of the occupational injuries and illnesses reported [1, 2]. According to OSHA statistics, about 12-14% of total disabling occupational injuries occur because workers do not wear the appropriate PPE [3]. This has influenced various global organizations to implement strategies that will ensure a safe working environment. Thus, various legislation and initiatives reinforce these aspects, including the European Parliament Resolution of 10 March 2022 on a new EU strategic framework for health and safety at work after 2020 [4]. Despite these efforts, workplace safety remains a substantial challenge in modern society, as evidenced by statistics on workplace accidents. Table 1 shows the occupational diseases (OD) compensations based on occupational cases in South Africa. PPE is essential to the industrial sector because it provides a basic level of worker safety. Its main goal is to serve as a barrier that protects employees from the many possible risks that are present in their workplace [3, 5]. This component becomes especially important when it is not practical to eliminate risks through engineering fixes or modifications to procedures. PPE is essential in sectors like building sites and chemical processing facilities where there is always a chance of danger. For example, using the proper PPE—such as gloves, aprons, and face shields—when handling hazardous items like chemicals, is essential to preventing burns to the skin and poisonous fume inhalation. Similar to this, PPE such as steel-toed boots, helmets, and protective goggles is necessary in mechanical settings to protect employees from physical harm brought on by equipment, falling items, or debris.

Table 1: Occupational diseases (OD) compensations based on occupational cases in South Africa

Occupational Disease	Year																
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2016	2017	2018	2019
Noise-Induced Hearing Loss (NHL)	1465	1952	2549	2724	1823	3228	2644	785	1123	-	-	-	-	145	279	249	118
Tuberculosis of the Lungs (in healthcare workers)	211	500	384	384	323	119	69	54	223	-	-	-	-	141	184	257	191
Occupational skin disease	217	203	203	227	203	204	142	92	45	-	-	-	-	-	-	-	-
Pneumoconiosis	193	182	302	189	109	261	172	102	87	-	-	-	-	-	-	-	-
Occupational asthma	104	168	214	165	103	12	109	80	59	-	-	-	-	24	28	27	20
Mesothelioma	201	20	17	28	16	47	29	22	12	-	-	-	-	-	-	-	-
Irritant-induced asthma	-	-	-	7	16	12	6	39	33	-	-	-	-	-	-	-	-
Lung Cancers	-	-	-	4	1	8	9	5	3	-	-	-	-	-	-	-	-
Chronic obstructive airways diseases	-	-	-	17	13	30	10	15	12	-	-	-	-	-	-	-	-
Diseases caused by chemical agent	-	-	-	69	15	35	323	105	98	-	-	-	-	-	-	-	-
Diseases caused by physical agents, excluding noise	-	-	-	-	-	14	10	27	31	-	-	-	-	-	-	-	-
Diseases caused by biological agents, excluding TB	-	-	-	75	228	275	144	75	63	-	-	-	-	-	-	-	-
Chemical exposure	-	-	-	-	-	-	-	-	-	-	-	-	-	64	68	35	41
Others[1]	970	1664	1349	1469	972	105	21	21	45	-	-	-	-	-	-	-	-

Total	**3361**	**4689**	**5018**	**5358**	**3822**	**4564**	**3720**	**3720**	**1895**	**1111**	**1475**	**2579**	**2579**	**374**	**559**	**568**	**370**

Soucrce: Colinet et al. [3]

Furthermore, industries such as coal mining are one of these industries that pose the most risk because of their hazardous activities, exposure to coal dust, harmful gases like methane, high noise levels, and the ongoing possibility of cave-ins or injury from equipment. It is important to use PPEs effectively to ensure adequate protection for miners' health and safety. Respirable dust, known to be less than 10 micrometers (μm) in size, can be inhaled into the gas exchange region of the lungs and has long been known to be a serious health threat to workers in many industries [3]. In coal mining, overexposure to respirable coal mine dust can lead to coal workers' pneumoconiosis (CWP), commonly known as black lung. CWP is a lung disease that can be disabling and fatal in its most severe form, progressive massive fibrosis (PMF) [5]. In addition, miners can be exposed to high levels of respirable silica dust, which can cause silicosis, another disabling and/or fatal lung disease. Once contracted, there is no cure for CWP or silicosis [3, 6]. The goal, therefore, is to limit worker exposure to respirable dust to prevent the development of these lung diseases.

Despite PPE's generally efficient use at workplaces to help mitigate some hazards, several concerns about the situation remain. Factors such as worker compliance, quality, and adaptation to the challenging work environment greatly influence the success of PPE. Therefore, it is critical to understand how effectively PPE works in various workplaces to raise safety standards and reduce occupational hazards. In order to assess the effectiveness of personal protective equipment (PPE) in workplace operations, this systematic review will look at how efficient it is in reducing occupational dangers, how difficult it is to deploy, and where it might be improved. This study adds to the continuous endeavor to improve safety procedures in various sectors by tackling these elements.

2 METHOD

2.1 Data search

Systematic literature reviews provide a basis for evidence-based research and the acquisition of thematic knowledge in a particular field of study. Understanding the current state of personal protective equipment (PPE) for coal miners is essential for the success of coal mining business operations and workers' health and safety. This research utilized the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol as illustrated in Fig. 2. Related studies were identified through searches in Web of Science, PubMed, Scopus, Science Direct, and Google Scholar. Some keywords used include: "effective PPEs", OR "personal protective equipment", OR "protective devices", "coal mines" OR "coal mining" OR "workplaces" OR "worker's compliance" OR "construction sector" OR miners OR "workers". No restrictions were placed on the articles' language or year of publication to ensure a comprehensive search, and the identified information was subsequently transferred into EndNote reference management software. To maximize the number of relevant studies, the reference lists of the identified articles were manually examined. Searches were last updated in December 2024. A manual search of the reviewed articles was also undertaken to access all desired articles and prevent the deletion of related ones.

2.2 Inclusion and Exclusion Criteria

The following papers were excluded from this study: 1) Studies focusing on workers in the non-industrial sector, 2) Studies not addressing PPE, such as those focusing solely on administrative or engineering controls. 3) Studies utilizing secondary data, such as scoping, literature, and systematic reviews, were excluded. 4) Conference papers, book chapters, and books were excluded. 5) Papers written in languages other than English were also excluded, and Studies with insufficient methodology or a lack of detailed analysis (e.g., those not describing the PPEs used in the field).

Additionally, these studies were included in the study: 1) Studies on other high-risk industries if the findings are transferable to mining (e.g., construction, oil, and gas). 2) Research that discusses Use of personal protective equipment (e.g., helmets, respiratory devices, protective clothing, smart PPE). 3) Primary studies including Experimental, observational, or simulation-based studies. 4) studies that discussed effectiveness of PPE in reducing workplace accidents, injuries, or hazards.

2.2 Study Selection, and Data Extraction

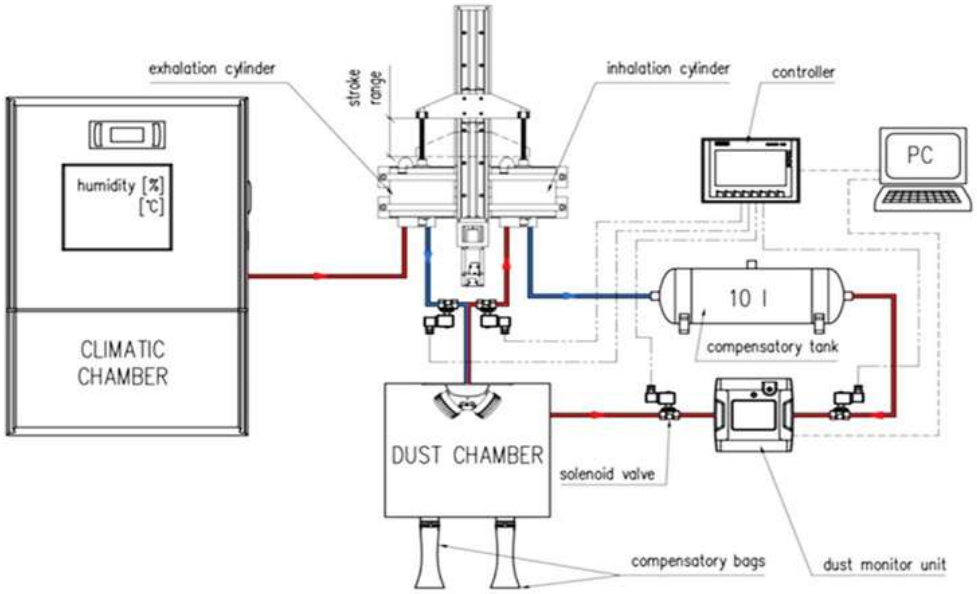

Fig 1 Schematic diagram of the test stand used for assessing half masks

This systematic review adhered to the established guidelines for systematic reviews and meta-analyses. In the initial stage of the PRISMA process, particularly during the identification of studies, duplicates found across different searched databases were removed. The preliminary selection and evaluation of articles were carried out by examining titles and abstracts, resulting in the elimination of unrelated articles according to the defined inclusion and exclusion criteria. The complete texts of articles were evaluated based on predefined inclusion and exclusion criteria. In the same manner, studies that were not relevant were omitted. To reduce bias, the reviewer carried out the evaluation of sources and data extraction independently at every stage. Data from all chosen studies were then gathered using a pre-prepared checklist. Also, a main schematic was deduced from the studies to explain how mask are being assessed as shown in Figure 1.

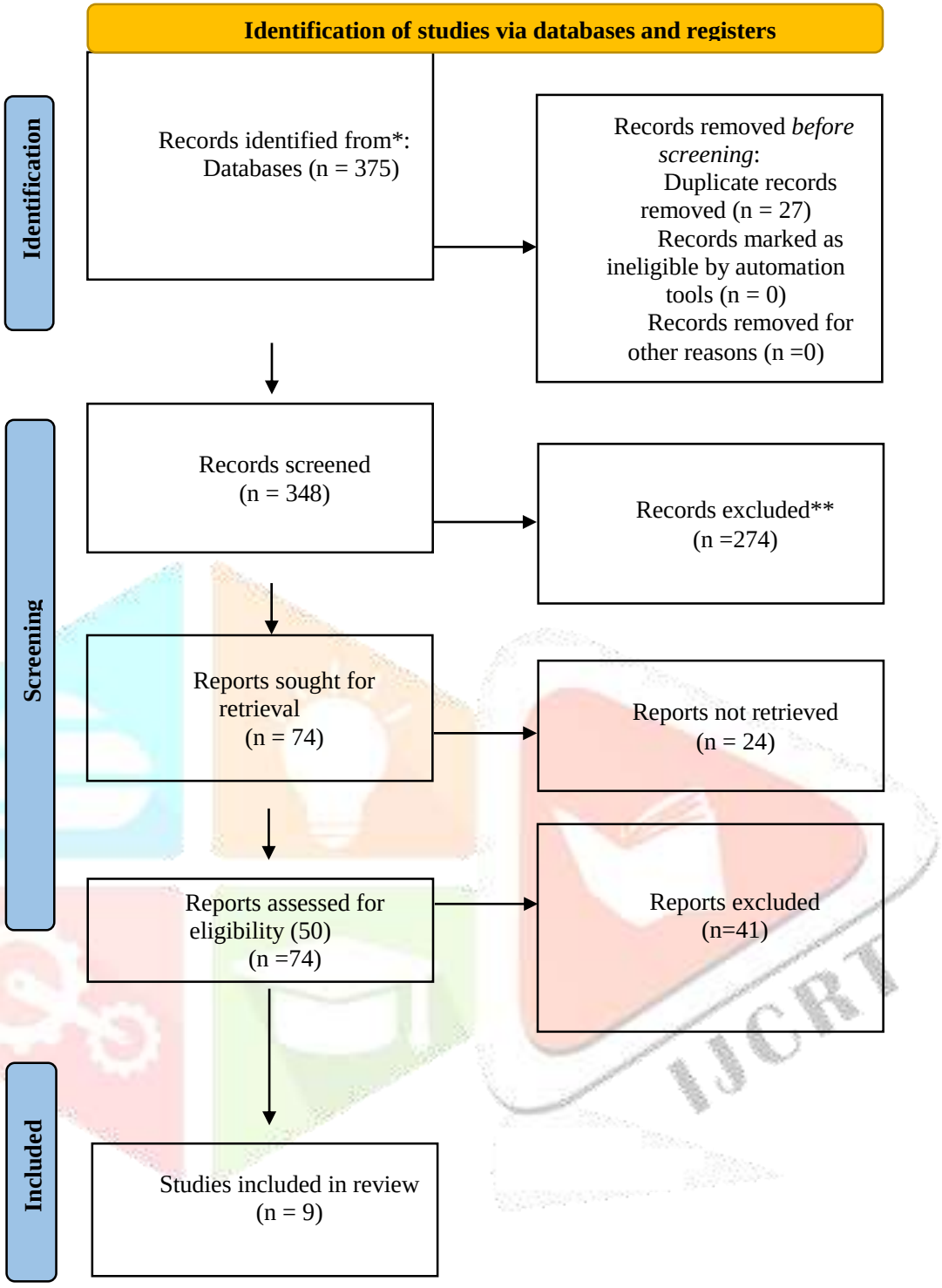

Fig. 2: PRISMA Flow Diagram for Study Selection

III. Results and Analysis

Table 2: Descriptive summary of the included studies

Study (year)	Location	Industry	Method	Sample size	Findings
Astuti (2023) [7]	Indonesia	textile	cross-sectional	100	Examined PPE usage habits among textile workers; identified factors influencing compliance.
Tristiana et al. (2020) [8]	Indonesia	sand and gravel mine	cross-sectional	118	Assessed PPE usage in sand and gravel mining; found low compliance rates and associated factors.
Wong et al. (2020) [9]	Hong Kong	construction	Face-to-face interview	60	Investigated PPE usage among construction workers; identified barriers to proper use.
Kinemelo and Kengele (2024) [10]	Tanzania	Mining	cross-sectional	120	Evaluated PPE usage in mining; found low compliance and factors affecting usage.
Sehsah et al. (2020) [11]	Egypt	Construction	cross sectional	384	Measured prevalence of PPE use and accidents among construction workers; identified associated factors.
Peyre-Costa et al. (2024) [12]	Norway, Sweden, and Finland	open pit miners	cross-sectional study	453	Studied PPE usage among open pit miners; found non-use common due to discomfort and other factor
Nikulin et al. (2019) [13]	Russia	Coal mine	cross-sectional study	>350	Examined PPE usage in coal mining; highlighted importance of safety culture in compliance.
Kursunoglu et al. (2022) [14]	Turkey	Mining	cross-sectional study	115	Assessed PPE usage habits among mining employees; identified factors influencing compliance
Apreko et al. (2015) [15]	Ghana	Artisans	cross-sectional study	200	Investigated PPE usage among artisans; found low compliance and factors affecting usage.

Table 2 depicts a wide array of the sectors which were included in the study. These sections span from textile, constructions, different types of mining as well as artisans. The purpose of the diversity is to ensure that the analysis captures a different sector in the industrial sector. Also, most of the works used a cross-sectional quantitative analysis which lays the basis for a meta-analysis however because of heterogeneity of the data, the study only focused on narrative synthesis. Based on this data, the study came up with themes such as types of PPEs used, the effectiveness of these PPEs and recommendations to encourage its use.

IV. DISCUSSION

4.1 Types of PPEs

Accidents at the workplace can be reduced by using PPE as a personal protective device during work. The use of PPE is one of the risk controls for accidents, and it can decrease the incidence of accidents at the workplace [8, 16]. According to data gathered from the sand and gravel mining site, there were still many work accidents and little PPE use by the employees. In the transport group, workers wore only clothing and caps, whereas in the exploitation group, they donned complete clothing, headgear, and a face cover to keep sand out of their ears. One key component of health and safety practices is the use of Personal Protective Equipment (PPE) [15]. The use of other PPE, such as eye protection and covers for the hands, feet, and nose, was underutilized. Across diverse industries and sectors worldwide, a variety of PPE is utilized in workplaces to reduce occupational hazards. Examples of such PPE's include: head protective equipment, hearing protection, respiratory protection equipment, protective clothing, hand protective equipment, foot protective equipment, fall protective equipment.

4.1.1 Smart Helmets

For instance, considering the head protective equipment: it is used as a defense against the head from external object and other factors of harm while working in sectors where the head is exposed to occupational risk. There is several head protective equipment across sectors. Let us consider a Nand Logic Smart Helmet (NLS Helmet) for people going in for extreme sports as shown in Figure 3 [13].

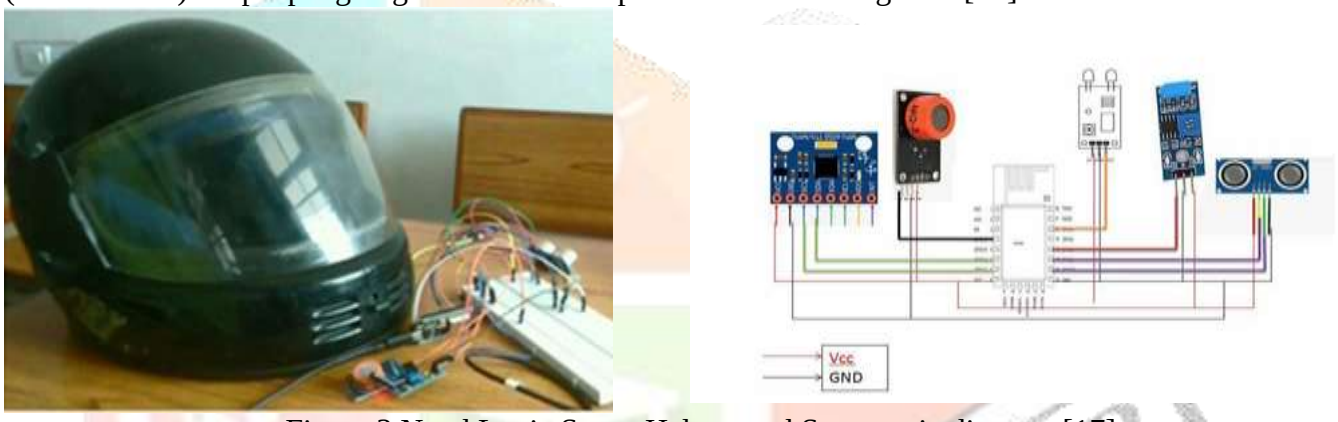

Figure 3 Nand Logic Smart Helmet and Systematic diagram [17]

NLS helmet consists of a safety helmet and an inbuilt electronic device. The electronic device contains many modules such as wireless Bluetooth connection, a GPS receiver, SD-card slot, stereophonic speakers, a battery, and cameras to record visual environment around the user, an accelerometer, a gyro sensor, light, temperature, and humidity sensors, as well as LEDs for information display. It also has an inbuilt alcohol sensor, which detects the alcohol consumption level of the driver; if the consumption level is high, the vehicle will not start [17]. The audio system of the helmet can be used to listen to audio information generated by a smartphone. The information from humidity and temperature sensors is assessed to automatically control fans integrated in the helmet to maintain a comfortable microclimate. A noise cancelling system is provided. Smart bicycles and crash helmets can be equipped with sensors to monitor the situation on the road and to timely warn drivers of an imminent danger [13].

Head protection is a fundamental aspect of occupational safety, particularly in industries and activities where there is a significant risk of falling objects, collisions, or other head injuries [18]. The use of helmets has evolved over the years, with advancements in technology allowing for the development of highly sophisticated models that go beyond basic impact resistance [19]. One of the key innovations in smart helmets is the ability to monitor and respond to environmental conditions [20]. Advanced models incorporate real-time data collection features, enabling them to assess external factors such as temperature, humidity, and air quality [21]. For example, sensors embedded in the helmet can detect hazardous levels of toxic gases in confined spaces, alerting the wearer to potential dangers and prompting immediate evacuation. Smart helmets are increasingly being equipped with augmented reality (AR) capabilities [21, 22].

4.1.2 Respirator protective equipment

Respiratory protective equipment is to prevent harmful chemicals, dust, smoke, and other harmful factors from entering the respiratory system by inhalation. This equipment includes various kinds of mask; such as nose mask, gas mask among others. These entire masks can be classified as half mask because it only has a portion, which covers the nose, and the other parts are the handles. Half masks are used to protect workers from potentially toxic coal dust [26]. This mainly focus on particulate matter in the size fraction PM2.5 which has an aerodynamic diameter less than or equal to 2.5 µm and can therefore penetrate into the deepest, alveolar regions of the lung [27]. In Figure 4 the reusable mask SECURA is showed. Reusable masks have two replaceable filters, which makes the active filtering area larger than for a disposable mask, which may affect the test results. Reusable masks are often tested in comparison with disposable masks [28]. There are two primary types of respirators: air-purifying respirators (APRs) and supplied-air respirators (SARs) [29, 30]. Air-purifying respirators are commonly used in workplaces with manageable levels of airborne contaminants [29]. These devices filter the air by removing particulates, gases, and vapors. Disposable masks, such as the widely recognized N95 respirators, are effective for short-term use and protect against fine particulates, including dust and biological particles [16, 31]. Reusable masks, on the other hand, are equipped with replaceable filter cartridges, making them suitable for prolonged use in environments with sustained exposure to harmful substances. Advanced versions of these respirators, known as powered air-purifying respirators (PAPRs), include battery-powered fans that reduce breathing resistance and enhance user comfort [32].

Figure 4 Example of the reusable mask SECURA 2000 [26]

Reusable masks have two replaceable filters, which makes the active filtering area larger than for a disposable mask, which may affect the test results. Reusable masks are often tested in comparison with disposable masks [28]. There are two primary types of respirators: air-purifying respirators (APRs) and supplied-air respirators (SARs) [29, 30]. Air-purifying respirators are commonly used in workplaces with manageable levels of airborne contaminants [29]. These devices filter the air by removing particulates, gases, and vapors. Disposable masks, such as the widely recognized N95 respirators, are effective for short-term use and protect against fine particulates, including dust and biological particles [16, 31]. Reusable masks, on the other hand, are equipped with replaceable filter cartridges, making them suitable for prolonged use in environments with sustained exposure to harmful substances. Advanced versions of these respirators, known as powered air-purifying respirators (PAPRs), include battery-powered fans that reduce breathing resistance and enhance user comfort [32].

The effectiveness of respiratory protective equipment is not solely dependent on its design but also on its proper use. Training programs play a crucial role in educating workers about the importance of proper fit and maintenance, as well as the risks associated with neglecting respiratory protection [33]. The application of RPE varies across industries, reflecting the specific risks associated with different work environments [34]. In recent years, environmental concerns surrounding the widespread use of disposable masks have gained attention. As a response, manufacturers have begun developing biodegradable materials and promoting reusable masks with replaceable filters [35]. These innovations aim to strike a balance between ensuring worker safety and minimizing environmental impact. Respiratory protective equipment is a critical component of workplace safety, offering invaluable protection against a wide range of airborne hazards. Its effectiveness hinges not only on technological advancements but also on proper usage, worker training, and a commitment to sustainability [36]. As industries evolve, continued investment in RPE innovation and education will remain essential to safeguarding the health of workers worldwide [37].

4.1.3 Protective Clothing

Protective clothing serves as a crucial barrier between workers and a wide array of occupational hazards, ranging from chemical spills and extreme temperatures to physical abrasions and biological contaminants. Its primary purpose is to safeguard the skin and body from exposure to harmful substances or environments, enabling workers to perform their tasks safely and effectively. Protective clothing is widely used across various industries, including construction, healthcare, chemical manufacturing, firefighting, and agriculture, each of which demands specific designs and materials tailored to the unique risks present in those fields. One of the most common types of protective clothing is chemical-resistant apparel. These garments are constructed using specialized materials such as polyethylene, polypropylene, or PVC, which provide resistance against chemical penetration and degradation. For instance, in laboratories or chemical plants, workers often wear suits designed to shield their skin from corrosive substances, toxic vapors, or hazardous liquids. Such clothing is often enhanced with sealed seams, hoods, and gloves to ensure comprehensive coverage, thereby minimizing the risk of accidental exposure.

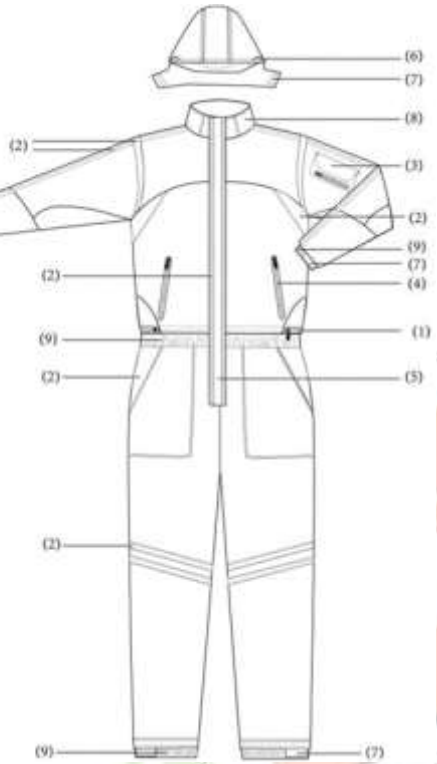

Figure 5 Design drawing of a multifunctional location mining uniform [38]

As shown in Figure 5, the waist zipper (1) can be pulled back from one side to the other opening side and is long enough to be self-wearing on and off and unobstructed. Both ends of the zipper are reinforced to prevent the material from being damaged by force, and to be durable. The shoulders, sleeves, plackets, pockets and knees are applied with fluorescent fabric (2). The fluorescent fabric meets the international standard of fluorescent agent content, is safe and non-threatening for human contact and, meanwhile, serves as a warning in case of poor lighting. The three-dimensional pocket on the sleeve has a built in GPS positioning system device (3) that can be removed and replaced to solve the problem of washing [39]. Front zippered pockets (4) prevent items from being dropped and lost while working. The front placket zipper (5) extends to the front crotch. Adjustable pull tabs are on both sides of the hat (6). Both sides of the hat can adjust the pulling button (6). Both sides of the hat, the sleeves and the hems are closed by Velcro tabs (7). The small stand-up collar (8), waist, cuffs and hems (9) are all elastic, and the tightened position reduces dust entry and is hygienic and germproof [38].

Heat-resistant clothing is another vital category, especially in industries where workers are exposed to high temperatures, molten metals, or open flames. Firefighters, for example, rely on flame-retardant suits made from materials like Nomex or Kevlar [27]. These fabrics are engineered to withstand intense heat and provide insulation against burns while remaining lightweight enough to allow for mobility [40]. Similarly, foundry workers use aluminized protective clothing to reflect radiant heat and prevent burns from molten metal splashes [41]. In contrast, cold-resistant clothing is indispensable for workers operating in sub-zero temperatures, such as those in the fishing, logistics, or arctic exploration industries. These garments are designed to retain body heat, often incorporating insulating materials like down or synthetic fibres [42].

Additionally, many cold-resistant suits are waterproof and windproof, protecting workers from frostbite and hypothermia in harsh weather conditions [43].

4.2 Effectiveness of PPE

The effectiveness of a PPE refers to how fit a PPE is and its ability to protect workers from occupational hazards at workplaces. Again, the effectiveness of a PPE should be able to measure the PPE's potential to mitigate disclosure to dangerous chemicals, physical risks, or environmental harm in workplaces. This can depend on several factors including fit and comfort, design and quality, type of hazard, its proper use and compliance

4.2.1 Compliance

Compliance with personal protective equipment can protect the body against the dangers of work accidents and technically can reduce the severity of work accidents. Personal protective equipment (PPE) does not eliminate or reduce existing hazards, it only reduces the amount of contact with hazards by placing barriers between labour and hazards [50]. Adherence is a positive behaviour of a person with a disease in achieving therapeutic goals. Obedience is a form of human behaviour that obeys the rules, orders set, procedures, and discipline that must be carried out (Komalig et al., 2019) [7]. According to Lawrence Green's theory (1980) [51], 3 main factors influence obedient behaviour, and obedient behaviour is influenced by 3 main factors: predisposing, enabling, and reinforcing factors. A predisposing Factor is a factor that facilitates or predisposes to the occurrence of a person's behaviour. These factors include knowledge, length of service, and level of education. Based on research Ariyanto (2023) [24] stated that there was a relationship between knowledge and compliance with the use of personal protective equipment (p-value=0.004). Individual knowledge cannot be separated from the level of education, the higher the education, the level of knowledge will increase, likewise in the behaviour of using personal protective equipment in industrial workers, the worker's education is related to the level of knowledge towards understanding the use of personal protective equipment. The higher the worker's education, the better the behaviour of using personal protective equipment [51]. Research Norvalinda et al., (2023) [52] stated that there was a relationship between length of service and discipline in using personal protective equipment (p-value=0.037). New workers tend not to be used to using personal protective equipment when working, so they feel uncomfortable and end up not using it. This is different from old workers who are used to working using personal protective equipment (Puji et al., 2017) [53]. The longer workers work, the more careful they will be because they understand the risks of working if they are not careful (Suganda, 2021) [54].

4.2.2 Fit and Comfort

The fit and comfort of PPE are fundamental in determining its effectiveness. If PPE does not fit correctly or is uncomfortable to wear, workers are more likely to remove it or adjust it in a way that compromises its protective capabilities [55]. For instance, respiratory masks that do not fit properly may allow harmful airborne particles to enter, rendering them ineffective. Similarly, poorly fitting gloves, boots, or protective clothing can lead to chafing or restricted movement, which may discourage workers from wearing them for extended periods. In addition to safety, comfort plays a significant role in compliance [56]. Workers are more likely to wear PPE consistently if it is designed for comfort, allowing for better mobility, breathability, and ease of use [57]. Comfort factors, such as adjustable straps, lightweight materials, and moisture-wicking fabrics, can help reduce fatigue, heat stress, and irritation, making it easier for workers to perform their tasks safely without being distracted by discomfort. For example, modern hard hats are now often designed with ergonomic padding, ventilation systems, and lightweight materials to improve comfort while still offering robust protection [58].

4.2.3 Design and Quality

The design and quality of PPE directly influence its protective capabilities. High-quality PPE is built using durable materials that are resistant to the specific hazards present in a given environment. For example, protective clothing used in chemical plants must be made from materials like Tyvek or PVC that can withstand chemical exposure, while flame-resistant clothing used in industries such as welding, or firefighting relies on materials like Nomex or Kevlar to protect against extreme heat [59].

In addition to material durability, the design of PPE should facilitate ease of use while providing comprehensive protection [60]. A well-designed item of PPE should cover all exposed areas without hindering the user's ability to move freely or perform essential tasks. For example, a fire-resistant suit for a firefighter should not only be flame-resistant but also flexible enough to allow for swift movement in dangerous

situations [61]. Similarly, hearing protection should be designed to block out harmful noise levels while still allowing the worker to hear important environmental sounds, such as warnings or instructions.
Moreover, PPE designs must be tailored to the specific risks of the workplace. In construction, for instance, helmets must not only protect against falling objects but also be designed with features like ventilation to keep workers cool in hot environments [11]. The design should also take into account the potential for long-term wear, ensuring that materials do not degrade quickly over time, especially when exposed to sunlight, chemicals, or physical strain. The highest quality PPE will include both performance testing and certifications to ensure it meets industry standards for safety and protection [61]. The effectiveness of PPE is determined by a combination of factors, including its fit and comfort, design and quality, and its suitability for the specific hazards encountered in the workplace. While PPE can significantly reduce the risk of injury and illness, its effectiveness is contingent upon these factors being properly addressed. PPE must fit well, be comfortable enough to wear for extended periods, and be made from high-quality materials that are appropriate for the hazards faced [62, 63]. With the right design, materials, and usage, PPE serves as an indispensable tool in safeguarding workers from a wide range of potential workplace dangers

4.3 Recommendations to Encourage Workers to Use PPE

Ensuring that workers consistently use Personal Protective Equipment (PPE) is critical to maintaining a safe work environment and preventing workplace injuries. Despite the availability of high-quality PPE, non-compliance remains a challenge in many industries, often due to factors like discomfort, lack of awareness, or a perceived lack of immediate risk. To improve PPE compliance and encourage workers to prioritize their safety, several strategies can be implemented. These recommendations focus on increasing awareness, improving comfort, fostering a safety culture, and ensuring effective enforcement of PPE usage.

4.3.1 Comprehensive Training and Education

One of the most effective ways to encourage the use of PPE is through comprehensive training programs that educate workers on the importance of PPE and how it helps to prevent specific risks in their work environment. Workers must be made aware of the potential dangers they face and understand that PPE is a critical line of defense [63]. Training should include demonstrations of how to properly wear, maintain, and store PPE. Additionally, workers should be informed about the limitations of PPE and the importance of using it consistently, even when they perceive the risks as low. Training should be interactive and ongoing, with refresher courses offered regularly to reinforce the importance of safety. Interactive elements such as simulations, case studies of actual workplace accidents, and discussions on the consequences of not using PPE can increase the impact of training sessions [64]. Visual aids and posters displayed in common areas can further remind workers of the risks they face and encourage them to take protective measures seriously.

4.3 2 Comfortability

Workers are more likely to wear PPE if it is comfortable and fits well. Uncomfortable or poorly designed PPE is a common reason for non-compliance, as workers may remove or adjust equipment to alleviate discomfort. To address this, employers should invest in high-quality PPE that is designed to provide comfort and protection. For example, breathable fabrics, adjustable straps, padded liners, and lightweight materials can enhance comfort, especially for workers who are required to wear PPE for extended periods. Employers should also ensure that PPE is available in a range of sizes to accommodate different body types. PPE that fits correctly not only enhances comfort but also improves safety by ensuring a proper seal and coverage [51]. Regular assessments of PPE effectiveness, with input from workers, can help identify areas for improvement in terms of both comfort and functionality [62].

4.3.3 Incentivize PPE Compliance

Incentive programs can be an effective way to encourage workers to consistently wear their PPE. Positive reinforcement through rewards or recognition can motivate workers to follow safety protocols. Employers can introduce reward systems where workers or teams who consistently wear PPE are recognized, rewarded with bonuses, extra time off, or even small prizes like gift cards or safety-related equipment. Incentive programs should be fair and achievable, with clear criteria for participation. For example, a “safety champion” program can reward employees who exemplify best practices in PPE usage, and monthly or quarterly safety performance reviews can help track compliance rates across teams or departments [65]. This approach helps create a culture of safety where wearing PPE becomes the norm and is celebrated as part of the company’s values.

4.3.4 Implement Strict Enforcement and Monitoring Systems

While positive reinforcement is essential, it's also crucial to implement strict enforcement policies to ensure compliance with PPE regulations. Clear and consistent rules about when and how PPE should be worn must be communicated to all employees. Supervisors should regularly monitor compliance, especially in high-risk areas or during dangerous tasks, and take corrective action when necessary.

Non-compliance should be addressed promptly, with appropriate disciplinary actions outlined in the company's safety policies. However, enforcement should be balanced with support—providing assistance to workers who may be struggling with the use of PPE, such as helping them find better-fitting gear or offering additional training, can address issues that contribute to non-compliance. Encouraging workers to use PPE consistently is essential for maintaining a safe and healthy work environment. By combining education, comfort, incentives, leadership, and effective enforcement, employers can create an environment where PPE use becomes second nature. When workers understand the importance of PPE, have access to comfortable and well-fitting gear, and are part of a safety-oriented culture, they are far more likely to adhere to safety protocols, reducing the risk of accidents and ensuring a safer workplace for all.

V. CONCLUSION

In conclusion, the effectiveness of Personal Protective Equipment (PPE) at workerplace is essential in safeguarding workers from the numerous and often hazardous conditions they face. The extraction and the manufacturing sectors are inherently dangerous industries, with risks ranging from exposure to harmful dust and gases to physical hazards such as falls, collisions, and equipment malfunctions. PPE plays a pivotal role in reducing these risks, provided that it is selected, used, and maintained appropriately. The key to PPE effectiveness lies in several factors, including proper fit and comfort, high-quality design, and the ability to address the specific hazards found at work environments. As discussed, PPE must be carefully chosen based on the hazards present, whether it be respiratory protection against coal dust, protective clothing to shield workers from physical injuries, or headgear and hearing protection to mitigate impacts and noise exposure. Additionally, the increasing sophistication of smart PPE, such as helmets with integrated communication systems, can provide added layers of protection by improving situational awareness and real-time data sharing. However, the effectiveness of PPE goes beyond just the equipment itself. Worker compliance, comfort, and proper training play critical roles in ensuring that PPE provides the intended protection. Ensuring that workers are adequately trained, that they understand the risks they face, and that they are encouraged and incentivized to use PPE consistently is just as important as the gear's physical features. Furthermore, a safety-oriented work culture and regular assessments of PPE usage can help address non-compliance and improve overall safety standards. To truly enhance PPE effectiveness in coal mines, it is essential that both employers and workers prioritize the adoption of high-quality, suitable PPE, foster a culture of safety, and continuously assess and adapt to emerging risks and technologies. Through a combination of proper education, employee engagement, and the use of advanced protective gear, coal mining operations can significantly reduce the incidence of workplace injuries and fatalities, ensuring a safer environment for all workers. In doing so, the coal mining industry can continue to advance in both productivity and worker well-being, setting a benchmark for other industries where high-risk environments exist.

REFERENCES

[1] Akbar-Khanzadeh F, Bisesi MS, Rivas RD. Comfort of personal protective equipment[J].Applied Ergonomics,1995, 26(3).195-198.
[2] LaBar G. OSHA plans updates of PPE rules[J].Occupational Hazards,1990, 52(6).51-53.
[3] Colinet J, Halldin CN, Schall J. Best practices for dust control in coal mining[J].2021.
[4] Pisu A, Elia N, Pompianu L, et al. Enhancing workplace safety: A flexible approach for personal protective equipment monitoring[J].Expert Systems with Applications,2024, 238.122285.
[5] Almberg KS, Halldin CN, Blackley DJ, et al. Progressive massive fibrosis resurgence identified in US coal miners filing for black lung benefits, 1970–2016[J].Annals of the American Thoracic Society,2018, 15(12).1420-1426.
[6] Reddy SC, Valderrama AL, Kuhar DT. Improving the use of personal protective equipment: applying lessons learned[J].Clinical Infectious Diseases,2019, 69(Supplement_3).S165-S170.
[7] Astuti D. Analysis of Predisposing Factors Related to Compliance With the Use of Personal Protective Equipment in the Textile Industry[J].Contagion: Scientific Periodical Journal of Public Health and Coastal Health,2023, 5(4).1284-1295.

[8] Rr Dian T, Pravitasari R, Erna DW. Contributing factors of personal protection equipment (PPE) utilization among sand and gravel (SSG) mine workers[J].International Journal of Psychosocial Rehabilitation,2020, 24(7).9035-9040.
[9] Wong TKM, Man SS, Chan AHS. Critical factors for the use or non-use of personal protective equipment amongst construction workers[J].Safety science,2020, 126.104663.
[10] Kinemelo E, Kengele KJ. Knowledge, Attitude and Practice on the Use of Personal Protective Equipment to Small Mining Industry at Kaboha Ward in Geita Region-Tanzania[J].The Nigerian Health Journal,2024, 24(4).1715-1721.
[11] Sehsah R, El-Gilany A-H, Ibrahim AM. Personal protective equipment (PPE) use and its relation to accidents among construction workers[J].La Medicina del lavoro,2020, 111(4).285.
[12] Peyre-Costa D, Stjernbrandt A, Wahlström J, et al. Self-reported exposure to dust and diesel exhaust, respiratory symptoms, and use of respiratory protective equipment among Arctic miners[J].International Journal of Circumpolar Health,2024, 83(1).2343125.
[13] Nikulin A, Ikonnikov D, Dolzhikov I. Smart personal protective equipment in the coal mining industry[J].International Journal of Civil Engineering and Technology,2019, 10(4).852-863.
[14] Kursunoglu N, Onder S, Onder M. The evaluation of personal protective equipment usage habit of mining employees using structural equation modeling[J].Safety and health at work,2022, 13(2).180-186.
[15] Apreko AA, Danku LS, Apeletey MS, Adokou FA. Occupational Health and Safety Management: the use of personal protective equipment (Ppe) by artisans in the local automotive industry in Volta Region, Ghana[J].Ghana Int J Eng Trends Tech,2015, 19.201-205.
[16] D DR. Keselamatan dan Kesehatan Kerja[J].(Yogyakarta: Deepublish),2016.
[17] Sobhana S, Sowmeeya SR, Srinathji M, Tamilselvan S. Smart Helmet. In.2021.IOP Publishing.012116.
[18] Adjiski V, Despodov Z, Mirakovski D, Serafimovski D. System architecture to bring smart personal protective equipment wearables and sensors to transform safety at work in the underground mining industry[J].Rudarsko-geološko-naftni zbornik,2019, 34(1).37-44.
[19] Ahmad A. Awareness of workplace hazards and preventive measures among sandstone mineworkers in Rajasthan, India: A cross-sectional study[J].Journal of Health and Social Sciences,2017, 2(1).69-82.
[20] Ammad S, Alaloul WS, Saad S, Qureshi AH. Personal protective equipment (PPE) usage in construction projects: A scientometric approach[J].Journal of Building Engineering,2021, 35.102086.
[21] Aram, Appah S, Saalidong BM, Appiah A. Implications of health, safety and environmental conditions on artisanal goldminers' self-protection at work in Ghana[J].2021.
[22] Aram SA. Managing occupational health among goldminers in Ghana: Modelling the likelihood of experiencing occupational related health problems[J].Plos one,2021, 16(7).e0254449.
[23] Aram SA, Saalidong BM, Appiah A, Utip IB. Occupational health and safety in mining: Predictive probabilities of Personal Protective Equipment (PPE) use among artisanal goldminers in Ghana[J].Plos one,2021, 16(9).e0257772.
[24] Ayoo BA, Moronge J. Factors influencing compliance with occupational safety regulations and requirements among artisanal and small-scale miners in central sakwa ward, siaya county[J].Journal of Sustainability, Environment and Peace,2019, 1(1).1-5.
[25] Baghaei Naeini SA, Badri A. Identification and categorization of hazards in the mining industry: A systematic review of the literature[J].International Review of Applied Sciences and Engineering,2024, 15(1).1-19.
[26] Drwięga A, Williamson B, Foster P, Lesiak K. Effectiveness of half masks for respiratory health protection in coal mining[J].Mining Machines,2021(3).
[27] Li D, Li Y, Li G, et al. Fluorescent reconstitution on deposition of PM2. 5 in lung and extrapulmonary organs[J].Proceedings of the National Academy of Sciences,2019, 116(7).2488-2493.
[28] Beth AA. Assessment Of Occupational Safety Compliance In Small-Scale Gold Mines In Siaya County, Kenya[J].2018.
[29] Botha D, Cronjé F. Occupational health and safety considerations for women employed in core mining positions[J].SA Journal of Human Resource Management,2015, 13(1).1-12.
[30] Chimamise C, Gombe NT, Tshimanga M, et al. Factors associated with severe occupational injuries at mining company in Zimbabwe, 2010: a cross-sectional study[J].Pan African medical journal,2013, 14(1).
[31] Eker H. A study on precautions to be taken in the event of a pandemic in the mining industry in Turkey[J].Balıkesir Üniversitesi Fen Bilimleri Enstitüsü Dergisi,2023, 25(1).49-64.
[32] Gridina E, Kovshov S, Borovikov D. HAZARD MAPPING AS A FUNDAMENTAL ELEMENT OF OSH MANAGEMENT SYSTEMS CURRENTLY USED IN THE MINING SECTOR[J].Scientific Bulletin of National Mining University,2022(1).

[33] Hermanus MA. Occupational health and safety in mining-status, new developments, and concerns[J].Journal of the Southern African Institute of Mining and Metallurgy,2007, 107(8).531-538.
[34] Imam M, Baïna K, Tabii Y, et al. Ensuring Miners' Safety in Underground Mines through Edge Computing: Real-Time Pose Estimation and PPE Compliance Analysis[J].IEEE Access,2024.
[35] Ismail SN, Ramli A. Investigate the factors affecting safety culture in the Malaysian mining industry[J].Resources Policy,2023, 85.103930.
[36] Jansen JC, Brent AC. Reducing accidents in the mining industry-an integrated approach[J].Journal of the Southern African Institute of Mining and Metallurgy,2005, 105(10).719-725.
[37] Krisnayanti BD, Vassura I, Asmara MD, et al. Analysis of artisanal small-scale gold mining sector in West Sumbawa Regency, Indonesia[J].Journal of Health and Pollution,2016, 6(12).26-33.
[38] Xiangfang R, Lei S, Xiying Z, et al. Design and research of life-saving cotton-blended miners' clothing[J].International journal of occupational safety and ergonomics,2022, 28(3).1430-1438.
[39] Kwesi SS, Dartey E, Kuffour RA, et al. Occupational Health and Safety Practices among Small-Scale Mining Workers in Ghana[J].European Journal of Science, Innovation and Technology,2024, 4(2).26-39.
[40] Maia F, Veiga MM, Stocklin-Weinberg R, et al. The need for technological improvements in Indonesia's artisanal cassiterite mining sector[J].The Extractive Industries and Society,2019, 6(4).1292-1301.
[41] Malema KM. Working environment versus workers' compliance with occupational safety and health protective equipment in Malawi's mining sector[J].Occupational Health Southern Africa,2021, 27(3).92-94.
[42] Martinez G, Smith NM, Malone A. Formalization is just the beginning: Analyzing post-formalization successes and challenges in Peru's small-scale gold mining sector[J].Resources Policy,2021, 74.102390.
[43] Mavhura E. A systems approach for assessing emergency preparedness in underground mines of Zimbabwe[J].Resources Policy,2019, 62.1-8.
[44] Mensah SK, Siabi EK, Donkor P, Kurantin N. Assessing the safety and health practices in the artisanal and small-scale gold mining sector of Ghana: A case of Ntotroso[J].Environmental Challenges,2022, 6.100443.
[45] Musah M. Health and safety compliance in the mining sector a case study on AngloGold Ashanti projects[J].2021.
[46] Nakua EK, Owusu-Dabo E, Newton S, et al. Injury rate and risk factors among small-scale gold miners in Ghana[J].BMC Public Health,2019, 19.1-8.
[47] Nikulin A, Nikulina AY. Assessment of occupational health and safety effectiveness at a mining company[J].Ecology, Environment and Conservation,2017, 23(1).351-355.
[48] Njumwa JZ, Nyame FK, Ofori BD, et al. On the Margins of the Mining Economy: Occupational Health and Safety in Artisanal Scale Gemstone Mining in the Mwatate-Voi Area, Taita Taveta County, Kenya[J].East African Journal of Environment and Natural Resources,2024, 7(2).99-116.
[49] Phiri A, Nyirenda W, Phiri E, et al. Assessment of Workers' Perception of Occupational Hazards at Nampundwe Mine in Zambia[J].medRxiv,2024.2024-2011.
[50] Quiroz D, Mesa MPQ, Salinas EO. Occupational Safety and Health Risks[J].2023.
[51] Reardon LM, Heberger JR, Dempsey PG. Analysis of fatalities during maintenance and repair operations in the US mining sector[J].IIE transactions on occupational ergonomics and human factors,2014, 2(1).27-38.
[52] Sabastian SK. Occupational health and safety practices among small scale mining workers in Ghana; a case study of Wassa Amenfi (West, East And Central) Municipals[J].2022.
[53] Sikana C. Examination of occupational health and safety systems in selected mining companies on the Copperbelt province of Zambia[J].2020.
[54] Susanto A, Khaliwa AM, Iqbal MR, et al. COVID-19 prevention and control: Mining industry responses to the pandemic[J].Kesmas: Jurnal Kesehatan Masyarakat Nasional (National Public Health Journal),2022, 17(2).
[55] Souza TP, Watte G, Gusso AM, et al. Silicosis prevalence and risk factors in semi-precious stone mining in Brazil[J].American Journal of Industrial Medicine,2017, 60(6).529-536.
[56] Wireko-Gyebi RS, Arhin AA, Braimah I, et al. Working in a risky environment: Coping and risk handling strategies among small-scale miners in Ghana[J].Safety and health at work,2022, 13(2).163-169.
[57] Singo J, Moyo D, Isunju JB, et al. Health and safety risk mitigation among artisanal and small-scale gold miners in Zimbabwe[J].International journal of environmental research and public health,2022, 19(21).14352.
[58] Yator MJ. Status of Occupational Safety and Health of Soapstone Mine Workers in Tabaka, Kisii County, Kenya[J].2024.

[59] Zungu LI. Occupational health and safety challenges reported by women in selected South African gold and platinum mines[J].Occupational Health Southern Africa,2012, 18(5).6-13.
[60] Siabi EK, Donkor P, Mensah SK, et al. Assessing the knowledge and practices of occupational safety and health in the artisanal and small-scale gold mining sector of Ghana: A case of obuasi[J].Heliyon,2022, 8(11).
[61] Sepadi MM, Chadyiwa M, Nkosi V. Platinum mine workers' exposure to dust particles emitted at mine waste rock crusher plants in Limpopo, South Africa[J].International journal of environmental research and public health,2020, 17(2).655.
[62] Seyedeh ABN, Adel B. Identification and categorization of hazards in the mining industry: A systematic review of the literature[J].2024.
[63] Rose A, Allen-Spies J. Occupational health and safety challenges among artisanal and small-scale diamond miners in Kimberley, South Africa[J].Occupational Health Southern Africa,2023, 29(1).13-20.
[64] Sherin S, Raza S, Ahmad I. Conceptual Framework for Hazards Management in the Surface Mining Industry—Application of Structural Equation Modeling[J].Safety,2023, 9(2).31.
[65] Singo J, Isunju JB, Moyo D, et al. Accidents, injuries, and safety among artisanal and small-scale gold miners in Zimbabwe[J].International journal of environmental research and public health,2022, 19(14).8663.