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Community pharmacy, Green mining, Mining pollution, Environmental health, Occupational health, Sustainable healthcare

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Green Mining, Medicine, And Sustainability: Community Pharmacists As Frontline Partners In Public Health Protection

Abstract

Mining is a necessary component of economic development, providing access to minerals that are needed for infrastructure, energy production, health-care technologies, transportation, and modern industries. But when mining occurs, it can release silica dust, contaminated water, toxic metals, acid mine drainage, and particulate matter, affecting both mining personnel and the surrounding community. The goal of green mining is to mitigate these impacts by implementing cleaner technologies, improving resource efficiency, minimizing waste, conducting environmental monitoring, and rehabilitating the mine site; however, public health support is also required. This narrative review examines the health threats associated with mining, the definition and merits of green mining, and the role of community pharmacists in protecting public health and promoting environmental sustainability in mining-affected communities. The literature was searched on PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar databases using selected keywords. Selected fundamental studies were included, and publications between 2015 and 2026 were prioritized. The evidence reviewed suggests that the community pharmacist can contribute to the process of green mining by carrying out health education, training awareness of exposure risk, early identification and referral of mining-related diseases, support for chronic diseases, medication therapy management, medication surveillance, occupational health counseling, telepharmacy, environmental health surveillance, and managing pharmaceutical waste, especially in remote and resource-constrained areas. Community pharmacists are available and untapped public health partners in mine-affected communities. They could enhance disease prevention and surveillance, environmental stewardship, community resilience, and sustainable healthcare delivery by being incorporated into multidisciplinary green mining programs.

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INTRODUCTION

Mining is not only a vital part of global economic development but also supplies materials and metals for infrastructure, energy production, healthcare technologies, agriculture, transportation, and modern manufacturing [1]. Significant demand for critical minerals has grown in recent years, as renewable energy systems, electric vehicles, battery technologies, and digital industries have increased. This rising demand has driven an increase in global mining activity and raised awareness of the importance of more responsible and sustainable mining practices [2,3]. Yet mining has significant environmental and public health implications, despite its socioeconomic importance [4-7].

Green mining has become a promising approach to sustainable mining that reduces the environmental, social, and health impacts of mining operations without sacrificing economic productivity. It focuses on cleaner technologies, water, energy, and raw-material efficiency, pollution prevention, waste minimization, environmental monitoring, mine-site rehabilitation, and local community involvement [8-10]. Despite the implementation of green mining technologies, health risks for miners and surrounding communities can still arise from exposure to PM, metal-bearing dust, and other contaminants [7,11]. Public health interventions should, therefore, be embedded within a green mining campaign that includes exposure prevention, early disease detection, chronic disease management, community-level monitoring, and health education and stakeholder engagement. Such integration is essential for identifying, mitigating, and monitoring mining-related health risks while promoting the well-being of mining communities [12-14].

Community pharmacists are among the most accessible health care professionals and are increasingly recognized for their roles beyond dispensing medicines. This entails providing counseling for patients, health promotion, preventive care, screening, referral, medication therapy management, support for chronic diseases, vaccinations, and adherence monitoring [15-17]. Increasingly, they are also responsible for aspects of public health related to pharmacovigilance, antimicrobial stewardship, environmentally sustainable pharmacy practice, and environmental health education [18-20]. In communities where mining has taken place community pharmacists could be important in raising awareness of people and workers about the health risks associated with exposure, encouraging them to take preventative measures, advising on smoking cessation, screening for chronic health conditions, recognizing early signs of a mining-related illness, and providing information on how to dispose of unused and expired medicines in manner that is environmentally responsible [16,17,21,22].

Current research literature has largely addressed mining-related environmental and occupational health risks, including exposure to mine dust, particulate matter, toxic metals, and other mining-associated hazards [6,11,7,14]. In isolation, community pharmacy studies have focused on pharmacists' roles in preventive care, health education, screening and referral, chronic disease support and management, vaccination, pharmacovigilance, antimicrobial stewardship, and environmental

sustainability in the community pharmacy environment [16-20]. But little has been done to integrate these two areas, especially the role of community pharmacists in public health protection and environmental sustainability in green mining communities. This is a significant gap, especially in isolated or resource-poor mining regions where a community pharmacy may be a community's first point of contact for health information. In this context, the present review aims to discuss the health hazards of mining, the green mining concept and its benefits, and the role of community pharmacists in public health protection in mining-affected communities. The review also emphasizes the importance of community pharmacy in health education, disease prevention, early detection of mining-related conditions, medication safety, environmental stewardship, and pharmaceutical waste management. It also addresses key issues and future directions for community pharmacists' participation in complex, interprofessional green mining and environmental health initiatives.

SEARCH METHODOLOGY

The literature search was conducted in major electronic databases, including PubMed, Scopus, Web of Science (WoS), ScienceDirect, and Google Scholar. The keywords used were: community pharmacy, pharmacist, green mining, mining pollution, environmental health, occupational health, and public health, which were combined in various ways. The search focused mainly on articles published between 2015 and 2026 to ensure the inclusion of recent and relevant evidence. Some publications were selected; however, these had already been published and contained foundational information regarding occupational health hazards, sustainable mining, or community pharmacy practice. If there was no interest in the subject in relation to mining and/or community pharmacy, and they were not published in English, they were not included in this paper. Selected articles were manually screened to identify articles that were relevant to the study.

GREEN MINING

Mining is a major part of the economy and a key contributor to global development, supplying the minerals and metals required for infrastructure, energy generation, manufacturing, transportation, healthcare technologies, and other modern industries [1]. There are also risks to the health and safety of miners and neighboring communities from mining. Particulate matter, silica-containing dust, airborne particles containing metals, toxic metals, and other pollutants can be released into the environment through activities such as drilling, blasting, crushing, excavation, ore processing, waste dumping, or disposal [6,11,23]. They can also affect air, water, and soil quality and lead to various health issues, including silicosis, pneumoconiosis, respiratory diseases, disorders related to toxic metal exposure, and other occupational or community health risks [7,24,25].

The significant occupational and environmental health risks associated with mining operations, along with the preventive measures, are summarized in Figure 1.

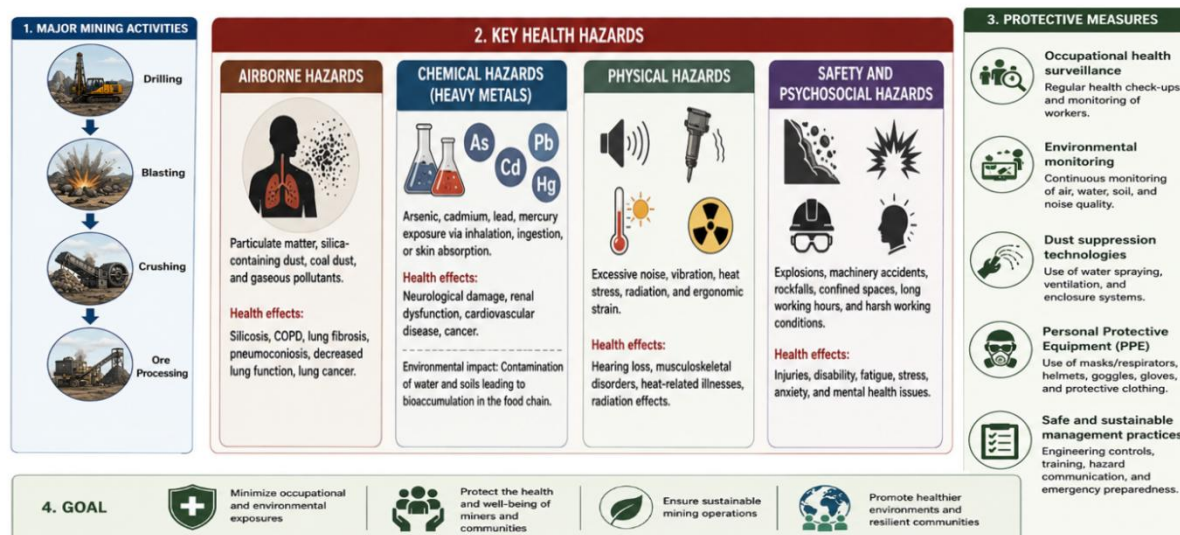


Figure 1. Major occupational and environmental health hazards associated with mining activities [6,7,11,23,24,25]

Green mining is defined as the use of environmentally responsible technologies, sustainable management systems, and resource efficiency to reduce the environmental, social, and human health impacts of mining while ensuring mineral productivity. It has come in response to rising concerns about environmental degradation, climate change, resource depletion, pollution, and the health risks associated with traditional mining methods. Green mining focuses on cleaner technology, efficient use of water, energy, and raw materials, pollution prevention, waste minimization, environmental monitoring, mine rehabilitation, and community involvement throughout the mining life cycle [8-10].

The green mining framework covers every phase of the mining process, from exploration and extraction, through mineral processing, to the closure of the mining area and post-mining rehabilitation of the land. It is about the efficient use of water, energy, and raw materials, with a particular focus on dust emissions and greenhouse gas emissions, acid mine drainage, and the release of toxic substances [9,26]. Trees, water, waste, soil, and environmental monitoring are increasingly supported by technologies such as precision mining, renewable energy systems, electrified mining vehicles, waste recycling systems, cleaner processing methods, and automated environmental monitoring systems in green mining practices [10,27] (Figure 2).

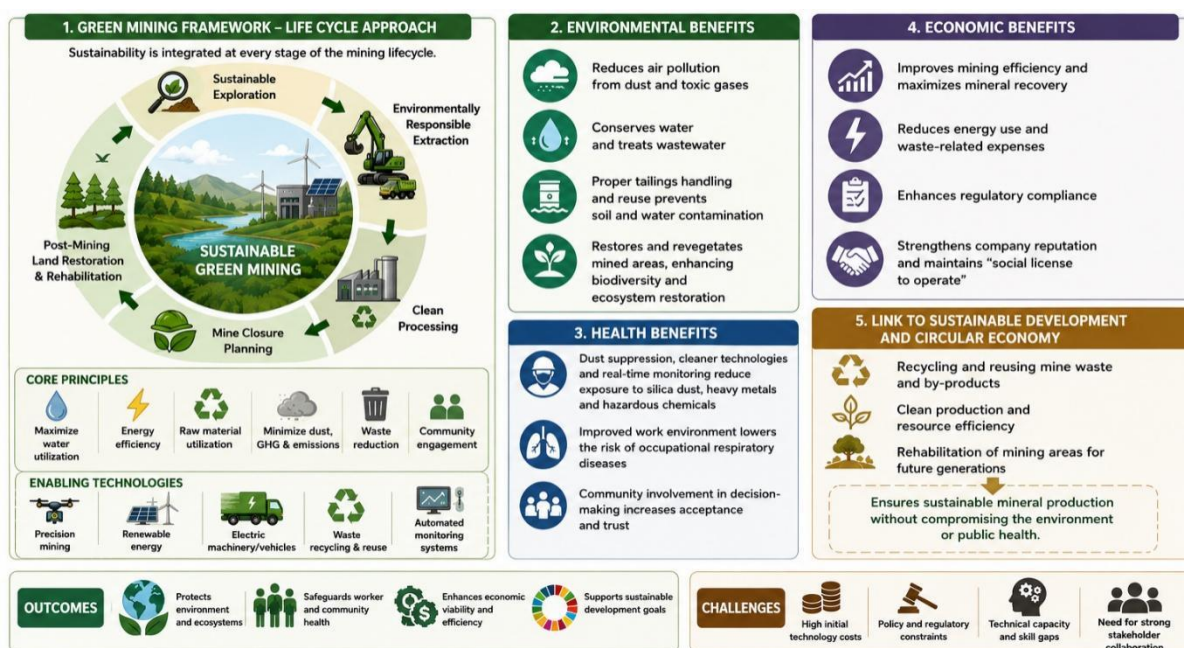


Figure 2. Conceptual framework of green mining and its environmental, health, economic, and sustainability benefits [8-10,26,27]

Green mining offers significant environmental advantages, including reducing pollution and improving resource efficiency. The use of sustainable mining practices and green technologies can minimize energy use, greenhouse gas emissions, chemical use, and waste generation, while improving environmental performance [10,28]. Furthermore, measures such as wastewater treatment, resource recovery, improved tailings management, and the reuse or recycling of mining waste can minimize contamination of surrounding ecosystems, agricultural land, and water bodies [29-31]. Moreover, rehabilitation and revegetation of the mines can promote soil stabilization, biodiversity protection, ecosystem productivity, and ecological restoration in mined areas [32].

Besides that, green mining can also help to ensure occupational and public health. These include cleaner extraction techniques, dust suppression systems, on-site environmental monitoring tools, and better waste management practices to minimize workers' and local communities' exposure to silica dust, metal-bearing airborne particles, heavy metals, and other hazardous airborne contaminants [7,11,23,24,33]. A healthier, cleaner mining environment can alleviate the burden of respiratory diseases, toxic exposures, and other mining-associated illnesses. Moreover, trust, social acceptance, and social license to operate for mining operations can be improved through community engagement, open dialogue, and equitable decision-making [34,35].

Economically, green mining can help optimize operational efficiency, minimize energy costs and material losses, maximize mineral recovery, and improve waste management through cleaner production, process optimization, recycling, and industrial ecology principles [10,36]. The use of renewable energy and resource-efficient technologies could further reduce reliance on fossil fuels, enhance operating margins, and mitigate the risk of energy price volatility in the mining industry [37]. Moreover, sustainable and socially responsible mining activities can boost the corporate image and enhance the mining firm's social license to operate by cultivating trust within the community, improving the quality of engagement, and ensuring fair procedures [34].

Green mining is closely related to sustainable development and principles of the circular economy. It encourages and recommends clean production, responsible use of natural resources, reuse and recycling of mining waste, improved tailings management, and rehabilitation of mining areas to support sustainable mineral production, whilst reducing environmental and public health risks [10,28,38]. Waste reduction, resource efficiency, and environmental contamination can be minimized through implementation of strategies that embrace circular economy principles, such as the reuse and recycling of mine tailings and other mining wastes

[30,31,39]. Another benefit of mine-site rehabilitation and ecological restoration is that it can help to safeguard ecosystems and surrounding communities in post-mining environments [32]. While technological, policy, and regulatory challenges may limit implementation, green mining is a key means of supporting sustainable mineral mining and environmental protection.

ROLES AND RESPONSIBILITIES OF COMMUNITY PHARMACY

Community Pharmacy is a readily available part of the health care system that plays an important role in disease prevention, health promotion, medication management, and patient education. Community pharmacists are at the heart of the care and use of medicines and play a significant role in ensuring rational, safe pharmaceutical use, providing dosage advice, managing adverse drug reactions and drug interactions, and minimizing medication-related problems. They also serve as preventive care providers, including offering immunizations, assisting with smoking cessation, monitoring blood pressure, conducting chronic disease screening, providing education, referring patients for services, and performing other clinical preventive services [16,40]. In the mining industry, these services are especially pertinent, as particulate matter, mine dust, toxic metals, contaminated water, and other mining-related pollutants can compromise the health of miners and nearby communities [11,41]. Community pharmacists can thus participate as health educators and raise awareness among the population about risks from environmental and occupational exposures, their prevention, smoking, healthy lifestyles, timely referrals, and the use of personal protective equipment. Besides, they can contribute to pharmacovigilance and medication safety by reporting adverse drug reactions, monitoring self-medication, and participating in drug safety programs [18]. They may also play a role in raising awareness for the proper disposal of unused and expired medications and curbing pharmaceutical residues in soil and water systems as a result of medicine take-back programs [42].

CONTRIBUTION OF COMMUNITY PHARMACY IN GREEN MINING

Community Pharmacists can play a role in Green Mining Communities in public health protection, disease prevention, medication safety, environmental awareness, pharmaceutical waste management, and the delivery of sustainable healthcare. Their accessibility, combined with their health education expertise, makes them potential partners with health care providers, public health authorities, environmental agencies, and local communities in health education, screening, referral, environmental risk awareness, and sustainability-related interventions [16,20,43,44].

Table 1. The role of community pharmacists in green mining and sustainable community health

Area of contribution	Key activities	Contribution to green mining and public health
Health promotion and disease prevention	Educate both miners and local communities about the health risks associated with mining, including inhalation of particulate matter, silica dust, metal dust, and other airborne particles; exposure to heavy metals; contamination of drinking water; and chemical pollutants. Provide education on preventive measures and early signs or symptoms of respiratory, dermatological, cardiovascular, and toxicological conditions [7,11,23,24].	Community pharmacists play key roles in reducing illnesses associated with exposure, encouraging early diagnosis of mining-related diseases, improving health literacy, and assisting with preventive health care services in mining-affected communities. They can also be used to help screen for respiratory disease and to help make a timely referral if symptoms are suggestive of asthma, chronic obstructive pulmonary disease (COPD), or exposure-related respiratory disease [22].
Early identification and referral to a physician of mining-related diseases	Report any signs or symptoms that might indicate an occupational or environmental exposure (chronic cough, shortness of breath, skin irritation, neurological complaints, and possible heavy metal toxicity) to doctors, occupational health services, or relevant public health services for diagnosis and management [7,11,22,24].	This contribution can support early intervention, minimize health issues resulting from mining-related diseases, and enhance the public health aspects of green mining by linking health care response to recognition of environmental exposures. Community pharmacists can also help with screening and referral for respiratory symptoms suggestive of asthma, chronic obstructive pulmonary disease (COPD), or other diseases related to respiratory exposures [16,17,22].
Environmental health surveillance	Document and flag signs of unusual patterns of respiratory disease, skin disease, unusual symptoms of toxic exposures, or increases in medicine use in mining communities. Relevant observations can be reported to public health, healthcare providers, or environmental authorities, as appropriate, to enable early detection of environmental health risks associated with mining [11,45].	To assist in community-level environmental health monitoring and early detection of health impacts from mining-related pollution, community pharmacists can play a role. They have the potential to enhance referral, early warning, and public health response systems in communities affected by mining [16,46].
Medication therapy management for miners and residents	Community pharmacists can advise patients suffering from chronic conditions, such as asthma, chronic obstructive pulmonary disease (COPD), hypertension, diabetes, cardiovascular disease, and other conditions related to exposure. They can monitor medication adherence, identify drug-related problems, prevent medication-related harm, and counsel patients on the safe and effective use of medicines [22,47-49].	Helps improve the management of chronic diseases among miners and residents who may be at risk from mining-related environmental exposures. Pharmacist-led medication therapy management can be used to minimize medication-related problems, enhance adherence, facilitate management of respiratory and cardiometabolic diseases, and potentially reduce avoidable healthcare utilization in mining-affected communities [40,47-49].
Occupational health support	Offer counseling and education to miners to quit smoking, get vaccinated, drink plenty of water, avoid heat stress, wear a respirator, use PPE, and seek medical attention for exposure symptoms as soon as they occur. Occupational health teams and community pharmacists can work together to reinforce safe working practices and contribute to preventive health campaigns [16,21].	These activities also promote workforce health by developing prevention strategies, reducing modifiable risk factors (e.g., smoking), facilitating early identification of symptoms and concerns related to exposure, and providing timely referrals for occupational health assessment. They can also be used to lower the risk of occupational disease and to facilitate safe mining practices in line with green mining [33].

Pharmaceutical waste management	Community pharmacists have the potential to promote rational medicine use, discourage unnecessary medicine accumulation or inappropriate medicine reuse, support medicine take-back schemes, and educate the public about the safe disposal of medicines that have been unused or have expired [42,50].	These activities help prevent pollution of water and soil systems, reduce environmental contamination from improperly discarded pharmaceuticals, and implement the pollution-prevention and sustainability targets of green mining [42,51].
Education in the community and awareness of the environment	Awareness programs on air pollution, safe drinking water, heavy metal exposure, sanitation, hygiene, nutrition, medication safety, and environmental protection can be conducted by community pharmacists for populations affected by mining activities. They could also be involved in community outreach programs, health camps, health-promotion campaigns, and environmental awareness programs [20,40,43,44].	Pharmacy-based activities can help increase environmental health literacy, encourage responsible health actions, enhance community resilience, and engage communities in sustainable mining, aligning with broader public health and environmental protection goals [34].
Collaboration with stakeholders	Community pharmacists can work with healthcare professionals, public health officials, environmental agencies, mining companies, nongovernmental organizations, and local authorities to implement health education, screening, surveillance, referral, and pharmaceutical waste management programs [16,44].	This fosters a multidisciplinary approach and enhances the linkages among public health, environmental protection, and sustainable mining. This partnership could improve community participation, foster trust, and help provide coordinated responses to health and environmental challenges associated with sustainable mining development [34,52].
Services for digital health and telepharmacy	Use teleconsultation, electronic health records, digital medication management systems, mobile health platforms, and remote counseling services to support patients in remote and/or geographically isolated mining communities [53-55].	However, digital health and telepharmacy services have the potential to enhance access to pharmacy and healthcare services in remote mining areas, to provide support for accessing medicines and chronic disease follow-up services, to assist with remote counseling and adherence monitoring, and also to potentially reduce unnecessary travel and corresponding healthcare-related carbon emissions [54,56].
Support for sustainable healthcare and SDGs	Promote rational use of medicines, prevention, vaccinations, reduction of waste, sustainable disposal of medicines, health education and sustainable pharmacy services [16,43,44]	The activities enhance environmentally friendly community pharmacy practice, public health protection, the medicine-related environmental footprint, and the integration of the role of a pharmacist with sustainable healthcare, environmental stewardship, responsible consumption, and the climate action agenda [20]

DISCUSSION

Green mining is an essential step in the shift from traditional mining methods to a more sustainable approach that prioritizes environmental, safety, public health, resource efficiency, and community engagement. All the evidence presented in this review shows that mining will continue to play a crucial role in economic development, as it provides the minerals needed to produce energy, build infrastructure, develop healthcare technologies, advance transportation, and support modern industries. Mining operations, however, are also associated with significant environmental and health risks, including particulate matter, silica dust, metal-laden airborne particles, toxic metals, polluted water, acid mine

drainage, and more [6,7,11,23]. The exposures can lead to respiratory disease, silicosis, pneumoconiosis, toxic metal disease, cardiovascular effects, and other workplace and public health issues [24,25].

Green mining involves applying cleaner technologies, improving water and energy use efficiency, minimizing waste, improving tailings management, monitoring the environment, rehabilitating mine sites, and circular economy-based reuse of mining wastes, which can help mitigate several hazards associated with mining [8-10]. However, technology alone can't sufficiently safeguard miners and communities nearby. Despite best practices in the extraction and disposal of waste materials, dust, metals, and other contaminants can still be present from

mining, especially in resource-poor or poorly monitored areas. Thus, other community-level public health systems to prevent exposure, early detection of disease, chronic disease management, health education, surveillance, referral, and collaboration with stakeholders should support green mining [12-14].

Community pharmacists can be an effective and convenient public health partner for the mining-affected communities in this context. With their established roles in preventive care, patient counseling, screening, referrals, and vaccination, as well as their involvement in adherence support, pharmacovigilance, and health promotion, there is a solid foundation for their engagement in community-level health protection [16-18]. Community pharmacies may be the first points of contact for miners and residents with cough, breathlessness, skin irritation, neurological complaints, medication-related problems, or symptoms suggestive of toxic exposure in areas where healthcare facilities are limited. Pharmacists may thus be involved in educating about health risks related to mining, smoking cessation, use of personal protective equipment, vaccination, hydration and heat-stress prevention, and timely referral for suspected occupational or environmental diseases [21,22].

Community pharmacists contribute to mining-affected communities in other significant ways, such as medication therapy management. Some mines and surrounding communities might be more susceptible to asthma, chronic obstructive lung disease (COPD), hypertension, diabetes, cardiovascular disease, and other chronic diseases that are affected or made worse by the environment. Medication review by a pharmacist, adherence monitoring, inhaler counseling, identification of drug-related problems, and chronic disease follow-up may enhance disease control and limit avoidable use of health services [47-49]. Additionally, community pharmacists can play a role in monitoring environmental health by recording unexpected trends in respiratory infections, skin diseases, symptoms of toxic exposure, or increased medicine use, and reporting them to healthcare providers or public health officials [46,45].

The management of Pharmaceutical waste can also link community pharmacy practice to the objectives of green mining. Inappropriate disposal of unused or outdated drugs may lead to pharmaceutical residues in soil and water systems, contributing to the environmental burden in the mining area. Community pharmacists are key stakeholders in the rational use of medicines, in preventing inappropriate accumulation and reuse of medicines, in supporting medicine take-back schemes, and in providing education to the public about medicine disposal [42,50,51].

To implement it in the future, community pharmacists need to be formally integrated into multi-disciplinary green mining programs of healthcare professionals, environmental agencies, mining companies, local authorities, and public health officials. Access to patient counseling, medication management, chronic disease monitoring, adherence support, and referral services may also be expanded in geographically isolated mining communities through digital health and telepharmacy [53-55]. In summary, community pharmacy's involvement in

green mining efforts can boost disease prevention, environmental protection, community preparedness, and sustainable health care provisioning.

CONCLUSION

Green mining is vital to efforts to minimize environmental, occupational, and public health impacts of mineral extraction, whilst ensuring economic productivity and the sustainable use of resources. But without cleaner technologies, dust, heavy metals, contaminated water, and other exposure-related hazards can continue to affect miners and nearby communities. Community pharmacists can contribute to various aspects of green mining initiatives by providing health education; early identification and referral for exposures; support for chronic disease management; medication safety; pharmacovigilance; occupational health counseling; telepharmacy; and pharmaceutical waste management. They have been incorporated into multidisciplinary mining health programs, which could positively impact prevention, surveillance, environmental stewardship, community resilience, and sustainable healthcare delivery in mining-affected communities. Community pharmacy should thus be acknowledged as a key player in public health initiatives to promote green mining and environmental sustainability initiatives.

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CONFLICT OF INTERESTS

The authors declare no competing interests.

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