



REVIEW | SJIP 2026

Physiological Responses to Underground and Water-filled Mining Environments: A Narrative Review with Emphasis on Sri Lanka and Asian Regions

M.A.L.D. Malwatta*

Department of Physiology, Faculty of Medicine, University of Ruhuna, Sri Lanka

Abstract

Underground mining operations, particularly in tropical and subtropical regions of Asia, expose workers to extreme environmental conditions that pose significant physiological challenges. Miners working in hot, humid, and poorly ventilated underground environments experience severe cardiovascular strain, thermal stress, respiratory complications, and kidney dysfunction. Asian miners, particularly those in India, Pakistan, Indonesia, and China, face unique challenges due to tropical climates, limited mechanization, and inadequate ventilation systems. Stress in underground mines leads to elevated heart rate, high core body temperature, severe dehydration, and impaired kidney function. Water-filled mining environments and dewatering operations compound these challenges by increasing humidity levels and limiting air circulation. Critical environmental thresholds have been identified, beyond which physiological strain becomes dangerous. Remedial measures include improved ventilation, cooling technologies, physiological monitoring, and work-rest regimens. Based on evidence synthesized from 134 studies, essential insights for occupational health practitioners, mining engineers, and policymakers working to protect miners in tropical and subtropical Asian regions, including Sri Lanka, have been provided.

Keywords: Human physiological responses, occupational health hazards, Southeast Asia, underground mining

1. Introduction

Underground mining represents one of the most physiologically demanding occupational environments globally, exposing workers to extreme heat, high humidity, poor ventilation, and physically intensive labor. As mining operations extend to greater depths, environmental conditions become increasingly hostile, with temperatures rising approximately 10°C per kilometer due to geothermal gradients and auto-compression¹. These challenges are particularly acute in tropical and subtropical Asia, where surface temperatures are already elevated and mining operations often lack advanced cooling infrastructure.

The Asian mining sector, encompassing major coal and mineral producing nations including India, China, Indonesia, Pakistan, and smaller operations in countries like Sri Lanka, employs millions of workers facing unique physiological challenges. Unlike mechanized operations in temperate regions, many Asian mines rely on manual

labor in hot, humid, and poorly ventilated conditions²⁻⁶. The combination of tropical climate, high humidity, limited ventilation, and water infiltration creates environmental conditions that push human physiological limits.

While limited published research specifically addresses Sri Lankan mining physiology, the country's environmental conditions closely parallel those documented in regional studies⁷. Sri Lanka's tropical climate features year-round high temperatures (27-32°C) and humidity (70-90%), similar to Indonesian and Indian mining regions. The country's underground mining operations for graphite, gems, and minerals face challenges, including limited mechanization, inadequate ventilation, and water infiltration during monsoon seasons. Sri Lankan miners likely experience physiological strain comparable to documented Asian patterns, including elevated cardiovascular stress, thermal strain, dehydration, and kidney function impairment. The monsoon climate (May-September and December-February) exacerbates humidity levels in underground operations, potentially creating conditions similar to

*Address for correspondence:

Dr. M.A.L.D. Malwatta
Department of Physiology, Faculty of Medicine, University of Ruhuna,
Galle - 80000, Southern Province, Sri Lanka
E-mail: ghananjane@med.ruh.ac.lk

How to cite this article: Malwatta MALD. Physiological responses to underground and water-filled mining environments: a narrative review with emphasis on Sri Lanka and Asian regions. SAAP J Integr Physiol. 2026;1(1): 19-25.

water-filled mining environments documented elsewhere. Applying evidence-based interventions from regional studies is therefore critical for Sri Lankan occupational health policy.

This review synthesizes evidence from 134 peer-reviewed studies to examine human physiological responses to underground and water-filled mining environments, with particular emphasis on Asian and Sri Lankan contexts. In this review, critical environmental thresholds have been identified, physiological strain patterns have been documented, and evidence-based interventions to protect miners in tropical and subtropical regions have been proposed.

2. Methods

2.1. Literature search strategy

The literature identification was conducted using a traditional keyword-based Boolean search strategy across multiple academic databases, including PubMed/MEDLINE, Google Scholar, and discipline-specific repositories. This structured approach utilized standardized Boolean operators (AND, OR, NOT) and wildcard characters (e.g., asterisks for truncation) to ensure comprehensive retrieval of relevant studies while maintaining high precision.

Specific search strings were developed for each research objective and iteratively refined. A primary search string used across all databases was: ("physiological" OR "heat stress" OR "thermal strain" OR "heart rate" OR "core temperature" OR "dehydration" OR "metabolic rate") AND ("mining" OR "miner" OR "underground" OR "water-filled" OR "flooded" OR "deep mine") AND ("Sri Lanka" OR "Ceylon" OR "Asia" OR "South Asia" OR "Southeast Asia" OR "tropical")

The use of this traditional Boolean approach allowed for the following:

- Precise control over the intersection of physiological outcomes and mining contexts.
- Explicit inclusion of historical terminology (e.g., "Ceylon" for older Sri Lankan records).
- Capture of varied occupational roles by using the truncation "miner" (to include miner, miners, mineralogy, and associated terms).
- Transparent and reproducible search protocols that can be

easily audited or replicated by other researchers.

To ensure no relevant regional studies were missed, supplementary searches were performed using specific local terminology, such as "plumbago" and "graphite" in combination with geographic identifiers. This manual keyword refinement process was essential for identifying older Sri Lankan medical reports and regional Asian occupational health studies that may not use modern standardized medical subject headings (MeSH).

2.2. Study selection and data synthesis

The literature search covered publications from 2000 to 2026, and encompassed the following:

- *Peer-reviewed journals:* Occupational medicine, mining engineering, environmental health, tropical medicine, and ergonomics.
- *Regional sources:* Sri Lankan medical journals, Asian occupational health publications, and regional mining safety reports.
- *Grey literature:* Mining authority guidelines, occupational health standards, and technical reports from Sri Lanka, India, Indonesia, and other Asian mining regions.
- *Historical literature:* Colonial-era medical reports on Sri Lankan mining conditions, particularly plumbago/graphite mining.

The various categories of search terms are listed below:

- *Physiological responses:* Heat stress, dehydration, cardiovascular strain, respiratory function, thermal comfort, hypoxia, metabolic rate.
- *Mining contexts:* Underground mining, deep mining, water-filled mines, flooded mines, gemstone mining, graphite mining, plumbago mining.
- *Geographic focus:* Sri Lanka, Ceylon, South Asia, Southeast Asia, tropical mining, Asian mining regions.
- *Occupational health:* Occupational exposure, worker health, mining safety, industrial hygiene.

2.3. Deduplication process

Given the use of multiple search platforms and databases, a rigorous deduplication process was followed to ensure each unique study was counted only once.

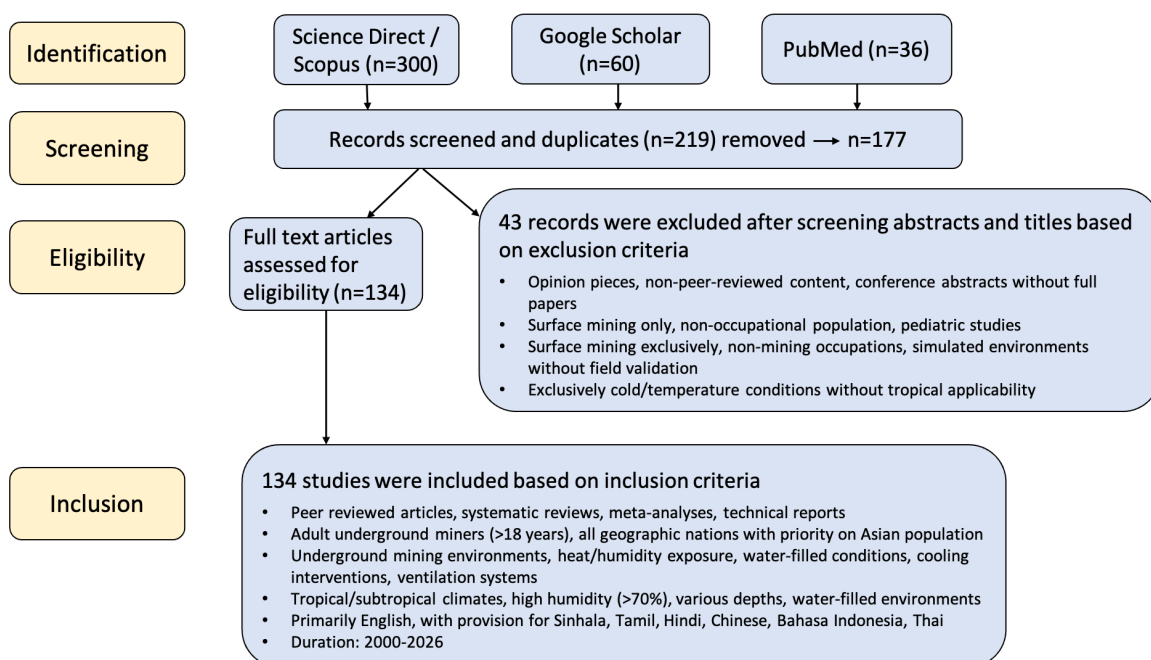


Figure 1: Study selection process

The types of deduplication strategies are highlighted below:

- **Automated deduplication:** Initial removal of exact duplicates based on Digital Object Identifier (DOI) matching across databases.
- **Title and author matching:** Secondary screening for papers lacking DOIs, identifying duplicates with minor title variations or author name formatting differences.
- **Manual verification:** Expert review of potential duplicates flagged by automated systems, particularly for regional studies with both English and local-language versions and historical papers with inconsistent bibliographic metadata.
- **Version control:** When multiple versions of the same study were identified, only the final peer-reviewed version was retained.

This rigorous process reduced the initial retrieval of 396 papers (ScienceDirect/Scopus: 300, Google Scholar: 60, PubMed: 36) to 177 unique records after the removal of 219 duplicates. Following title and abstract screening, 43 records were excluded, leaving 134 unique papers for final eligibility assessment and inclusion in the study (Figure 1).

3. Results and Discussion

3.1. Cardiovascular responses

Underground mining imposes severe cardiovascular strain, particularly in hot, humid Asian environments. Indian coal miners demonstrated working heart rates of 117-122 bpm with net cardiac cost of 49.7-54.8 bpm and relative cardiac cost of 47-52%. Recovery heart rates were poor, exceeding recommended cardiac strain levels⁸. Pakistani heat-exposed coal cutters showed elevated heart rates of 70.0±8.5 bpm post-shift⁹. Indonesian miners experienced significant heart rate increases from 77.76±8.34 to 92.14±9.15 bpm during shifts¹⁰. Continuous heart rate monitoring in various studies confirmed sustained cardiovascular stress throughout work periods¹¹⁻¹³. The combination of physical labor, heat stress, and inadequate recovery periods creates cumulative cardiovascular burden that may contribute to long-term cardiac health risks. Cardiovascular strain correlates strongly with environmental conditions. Studies documented that heart rate and blood pressure increase with ambient temperature, metabolic rate, and working time^{14,15}. Labor intensity and working time are direct factors, while ambient temperature acts as an indirect cause.

3.2. Thermal strain and core temperature regulation

Core body temperature regulation is severely challenged in underground mines. Pakistani coal cutters in hot mines reached core temperatures of 38.8°C versus 37.9°C in non-hot mines, while skin temperatures rose to 36.5°C in heat-exposed workers, approaching dangerous hyperthermia thresholds. In simulated hot-humid deep mine conditions (29-32°C; 0.8-1.8 m/s air velocity), mean skin temperature (T_{msk}) and oral temperature (T_{or}) increased with air temperature and labour intensity, but decreased with higher air velocity¹⁶. Maximum acceptable skin temperature thresholds were 36°C (acceptability) and 35°C (comfort)¹⁷; sweat loss and heart rate were driven mainly by labor intensity¹⁸. Modified predicted heat strain models for hot-humid underground settings (air velocity 0.3-0.8 m/s; relative humidity 50-80%) showed air velocity affects allowable exposure time more than humidity, improving acceptability from 33.65% to 91.35% at moderate metabolic rates¹⁹. High humidity (80-96%) may also impair respiratory heat dissipation²⁰. Kidney strain is prominent: Pakistani miners showed post-shift eGFR decline (100±19 to 94±9), reduced hematocrit (45.4±1.4 to 43.6±2.1), and serum osmolality >290 mmol/L in 100% post-shift²¹. Indonesian miners had increased urine specific gravity (1008.81±5.23 to 1012.76±5.01)²². Moreover, heat-exhaustion can be associated with inflammatory and metabolic changes, as well as low-fluid intake, leading to elevated chronic kidney disease (CKD) risk in hot and humid mines.

3.3. Cognitive performance and fatigue

Heat and humidity significantly impair cognition and increase fatigue. A study showed that higher temperature and humidity reduced miners' attention, reaction capability, and cognitive capability while increasing fatigue severity and error rates. Critical thresholds were 37°C and 80% relative humidity²³. Physiological measures, such as systolic blood pressure, heart rate, respiratory rate, typing speed, and memory level percentage, were negatively correlated with temperature and positively correlated with humidity²⁴. These deficits raise accident risk in hazardous mines. On extended shifts (10-12.5 h), fatigue peaked early and workers self-paced, yet 32-43% muscle force loss by shift end suggests cumulative fatigue persists^{25,26}.

3.4. Environmental factors and critical thresholds

Critical environmental thresholds beyond which physiological strain becomes dangerous have been identified in several studies^{27,28}. These are presented in Table 1 and summarized in Figure 2.

Table 1: Environmental thresholds and corresponding physiological strain

Environmental threshold	Physiological strain
Temperature	
Wet Bulb Globe Temperature (WBGT) >31°C	Heat exhaustion
Dry bulb temperature >37°C	Cognitive impairment
Air temperature 29-32°C	Significant thermal strain
Humidity	
Relative humidity >80%	Cognitive and physiological impairment
Humidity: 96%	Severe impairment of thermoregulation and muscle function
Combined conditions	
37°C + 80% humidity	Critical combined threshold
WBGT 31.5°C (range 25.2-35.3°C)	Heat exhaustion risk
High temperature + high humidity + low air velocity (0.1 m/s)	Severe physiological strain

In the Asian context, mines impose higher physiological strain than Western sites due to multiple interacting environmental and operational factors. Recognizing these regional differences is essential for designing effective interventions for Sri Lankan and other Asian mining contexts.

3.5. Climate and baseline environmental conditions

Tropical and subtropical climates across Asia maintain high baseline heat (27-32°C) and humidity (70-90%) year-round, leaving miners with a reduced thermal gradient for heat loss even before entering mines. Geothermal heating (~10°C per km depth) can push underground temperatures to 35-40°C or higher. High humidity severely limits sweat evaporation, the main cooling mechanism during heavy work, especially above ~80% relative humidity, forcing reliance on less effective convective and radiative cooling in hot air. Monsoon seasons further raise humidity toward saturation and increase water infiltration, driving underground humidity to 95-100% and virtually eliminating evaporative cooling.

3.6. Mechanization and work intensity

Limited mechanization in many Asian mines increases metabolic heat via intensive manual labor. Indian studies documented energy expenditures of 9.4-22.8 kJ/min during mining tasks, typically exceeding 33% of workers' maximal work capacity²⁹, generating substantial internal heat. Mechanized Western operations reduce individual metabolic demands through equipment use, lowering heat production. Manual drilling, loading, hauling, and support work require sustained high effort. Indian coal mine dressers showed working heart rates of 117-122 bpm with net cardiac cost of 49.7-54.8 bpm. Pakistani coal cutters reached core temperatures of 38.8°C. Muscle force degraded 32-43% by shift end in Indian mining machine operators. This demonstrates that the combination of high metabolic demands and impaired heat dissipation creates life-threatening thermal strain³⁰.

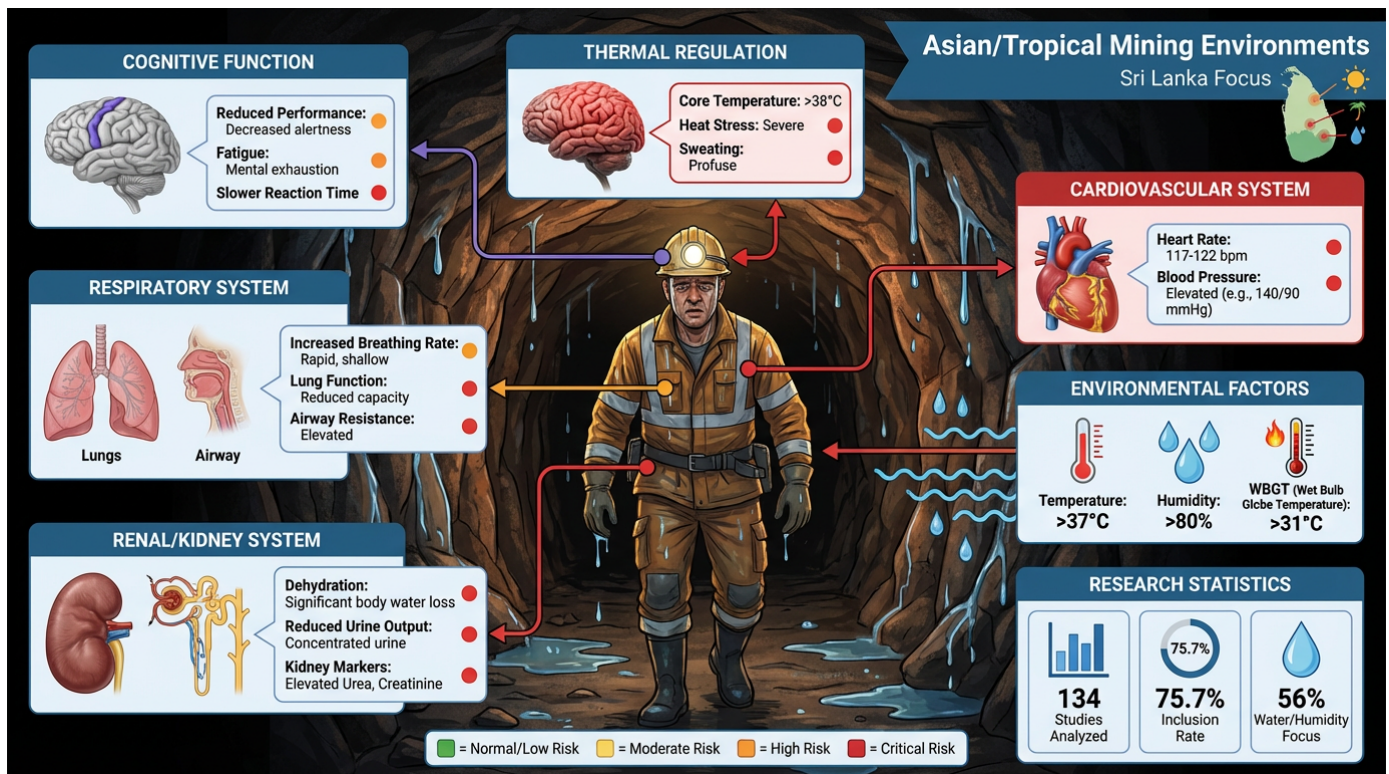


Figure 2: Key physiological responses in mining environment

3.7. Ventilation infrastructure

Inadequate ventilation is common in Asian mines due to resource constraints, technical limitations, and the difficulty of ventilating deep, complex networks. Indonesian mines reported air currents of only 0.1 m/s, far below the ≥ 0.5 m/s recommended for effective heat dissipation. In Pakistan, poor ventilation was associated with higher core temperatures (38.8°C vs. 37.9°C) and kidney dysfunction (eGFR decline of 6 mL/min/1.72m² per shift) compared with better-ventilated sites⁹. Key barriers include limited capital, power constraints, complex geometries, poor maintenance, and knowledge gaps. In contrast, Canadian and Australian mines often use refrigeration and continuous monitoring³¹.

3.8. Water infiltration and dewatering

Monsoon climates and high-water tables in many Asian regions increase water infiltration into underground mines. In warm working conditions, infiltrated water evaporates, pushing humidity toward saturation and reducing air movement. Dewatering pumps, though essential, add heat and can disturb ventilation patterns. During monsoon periods, partially flooded areas can eliminate evaporative cooling and force awkward postures that raise metabolic demands. Together, high humidity, elevated temperatures, and greater work intensity create dangerous thermal stress. In Sri Lanka, Southwest (May-September) and Northeast (December-February) monsoons can bring 200-300 mm/month rainfall, likely producing almost 100% humidity conditions, similar to wet-season Indonesian mines.

3.9. Mining depth and geothermal gradients

Increasing mining depth intensifies heat stress via geothermal gradients and auto-compression. Indonesian studies report $\sim 10^{\circ}\text{C}$ per km rise from geothermal heating and adiabatic compression of ventilation air¹⁰. As Asian mines go deeper, this becomes a critical challenge^{28,32}. At 500m, geothermal heating may add $\sim 5^{\circ}\text{C}$; with 30°C tropical surface temperatures, conditions reach $\sim 35^{\circ}\text{C}$. At 1000m, temperatures may exceed 40°C . Australian mines below 1200m show higher heat exhaustion incidence¹⁸. Asian mines at similar depths likely face greater risk due to hotter surfaces and poorer ventilation.

3.10. Socioeconomic and regulatory factors

Asian mining operations often lack resources to implement heat-stress controls. Small-scale and artisanal mines in Sri Lanka, Indonesia, and the Philippines may not be able to afford ventilation upgrades, cooling systems, or physiological monitoring. Regulatory enforcement and occupational health infrastructure can be limited. Workers may have low health literacy and poor access to healthcare in rural mining areas, reducing prevention, monitoring, and treatment of heat-related illness and compounding environmental and technical challenges.

4. Synthesis: The Asian Mining Challenge

Asian mines face a "perfect storm" of heat and work stressors that differs from temperate settings. Tropical temperatures, high humidity, limited mechanization, poor ventilation, water infiltration, increasing depth, and socioeconomic constraints combine to push miners to or beyond safe physiological limits. Sri Lankan graphite and gem mines share these conditions, typically $27\text{-}32^{\circ}\text{C}$ with 70-90% humidity, weak ventilation, monsoon-related flooding, and limited resources. So, miners likely experience strain similar to patterns reported in India, Pakistan, Indonesia, and China. Regional evidence highlights serious risks and guides locally adaptable interventions.

5. Recommendations

Based on the synthesis of engineering, administrative, and physiological evidence, the following integrated recommendations are proposed for underground mining operations in Sri Lanka and comparable Asian tropical settings:

5.1. Environmental monitoring and exposure thresholds

Continuous monitoring is vital for heat-stress management in underground mines. Measurement of ambient temperature, relative humidity, WBGT, and air velocity at all active working faces is required. Setting action thresholds is vital. It should be noted that WBGT $>28^{\circ}\text{C}$ warrants increased monitoring, $>30^{\circ}\text{C}$ requires work-rest modifications, and $>32^{\circ}\text{C}$ requires restriction of operations. Minimum air velocity ≥ 0.5 m/s should be maintained to reduce convective heat load³³.

5.2. Ventilation and cooling strategies

Mine ventilation systems should be upgraded to ensure adequate airflow and air velocity at working faces, especially in deep or poorly ventilated areas. Where ventilation is inadequate, supplementary cooling should be added, including refrigeration systems, cooling stations, and spot cooling. Ventilation design should account for monsoon-related seasonal humidity increases. Emerging adjuncts, such as phase change material-based cooling garments, may be used when engineering controls are constrained.

5.3. Work organization and administrative controls

Administrative measures reduce heat strain. Work-rest schedules should be based on WBGT and task-specific metabolic demands, using indices such as the thermal work limit (TML) to guide safe exposure durations³⁴. Under high heat stress, shifts should be limited to a maximum of eight hours and rest periods should be increased when thresholds are exceeded. Heavy work should be scheduled during cooler periods where feasible, and shaded or cooled rest areas should be provided with fluid access.

5.4. Hydration and nutritional management

Adequate hydration is central to preventing heat stress. Mining operations should provide unlimited access to cool, potable water with appropriate electrolyte supplementation³⁵. Structured hydration protocols should be implemented, targeting ~1.0-1.5 L/h during high thermal exposure¹⁸, consistent with underground mining observations and sweat rates in hot, humid conditions. Recommendations should be individualized by environment, work intensity, acclimatization, and shift length. Workers should be trained to recognize early dehydration and heat-illness signs.

5.5. Physiological monitoring and health surveillance

Routine monitoring enables early heat-strain detection and prevention. Pre-shift screening should assess hydration (e.g., urine specific gravity) and cardiovascular fitness. In high-risk heat, continuous or periodic heart-rate monitoring should be done. Post-shift checks should evaluate hydration, blood pressure, and symptoms. Long-term surveillance should track renal and cardiovascular health in chronically exposed workers³⁶.

5.6. Heat acclimatization and training

Structured heat-acclimatization should be made mandatory for new and returning workers, using 7-14 days of progressive heat exposure with monitoring of cardiovascular and thermal responses. Heat-stress awareness training should be given to all underground workers. Additionally, supervisor training in heat-illness recognition, first aid, and emergency response should also be provided.

5.7. Personal protective equipment optimization

Personal protective equipment (PPE) should be evaluated for thermal burden. Where safety standards permit, lightweight and breathable clothing should be provided to minimize heat retention. Cooling garments and phase change material technologies may be piloted in high-risk environments, particularly where engineering controls cannot be fully implemented³⁷.

5.8. Research, data collection, and regional collaboration

Systematic collection of environmental and physiological data is needed in Sri Lankan and other Asian mining populations. There is a need to establish baseline physiological profiles and conduct site-specific heat stress assessments to guide locally appropriate interventions. Collaboration with regional research institutions is required in order to develop evidence-based, context-sensitive heat mitigation strategies. Moreover, best practices should be shared across Asian mining operations.

5.9. Policy development and regulatory enforcement

There is a need to develop and enforce national occupational health

and safety standards for tropical underground mining, mandating environmental monitoring, physiological surveillance, heat-stress training, and emergency preparedness³⁸. Moreover, regulations should add enforcement, non-compliance penalties, and technical support for resource-limited small-scale mining operations³⁹.

5.10. Emergency preparedness and response

All mining operations should establish formal heat illness emergency response protocols⁴⁰. These should include access to cooling facilities, medical supplies, trained first responders, and clear evacuation procedures for extreme heat events. Regular drills and protocol reviews should be conducted to ensure preparedness and effectiveness.

6. Conclusion

Underground mining in tropical and subtropical Asia, including Sri Lanka, exposes workers to extreme physiological challenges beyond those in temperate operations. Across 134 studies, miners show severe cardiovascular strain (117-122 bpm), dangerous heat stress (core temperature >38°C), dehydration and kidney dysfunction (eGFR drops 6-10 mL/min/1.72m² per shift), and cognitive impairment under conditions often exceeding critical thresholds (WBGT >31°C, humidity >80%, temperature >37°C). Tropical climate, limited mechanization, poor ventilation, and water infiltration intensify risks. Sri Lankan mines mirror regional patterns. Evidence-based measures, such as ventilation and cooling upgrades, adequate work-rest cycles, hydration, and monitoring, are feasible and urgently needed.

Funding

No funding was received for writing the article.

Conflict of Interest

The author is on the Editorial Board of the SAAP Journal of Integrative Physiology.

Authors' Contributions

The author conceptualized the topic, performed the literature search, and wrote the manuscript.

Disclosure

The AI tool, SciSpace (version 1.5.1) was used to create the image presented in Figure 2.

References

- Jia C, Xie Y, Dai L, Shi C, Lei M, Zheng Y. Detailed thermal environment classification of high geothermal tunnel based on thermal comfort indices. *Build Environ*. 2024;266(6):112135. DOI: 10.1016/j.buildenv.2024.112135.
- Saha R, Dey NC, Samanta A, Biswas R. A comparative study of physiological strain of underground coal miners in India. *J Hum Ergol (Tokyo)*. 2007;36(1):1-12. PMID: 18517022.
- Liu G, Liu H, Chen F, Wu S, Wu G. The effect of environmental variables and metabolic rate on physiological parameters in a hot and humid mine. *Sci Technol Built Environ*. 2022;28(4):451-66. DOI: 10.1080/23744731.2021.2000781.
- Susanto A, Purwanto P, Sunoko HR, Setiani O. Assessment of diesel particulate matter exposure of underground miners in Indonesia. *J Ecol Eng*. 2018;19(4):34-42. DOI: 10.12911/22998993/89671.
- Dissanayake C. Of stones and health: medical geology in Sri Lanka. *Science*. 2005;309(5736):883-5. DOI: 10.1126/science.1115174.
- Pal AK, Sinha DK. The energy cost of metalliferous mining operations in relation to the aerobic capacity of Indian miners. *Ergonomics*. 1994;37(6):1047-54. DOI: 10.1080/00140139408963717.

7. Dassanayake WLP. Health of plumbago workers in Ceylon. *Br J Ind Med*. 1948;5(3):141-7. PMID: 18873552.
8. Saha R, Samanta A, Dey NC. Cardiac workload of dressers in underground manual coal mines. *J Inst Med Nepal*. 2010;32(2):11-17. DOI: 10.3126/joim.v32i2.4938.
9. Ijaz M, Ahmad SR, Akram M, Carter WS. Workplace induced heat-related-illness and kidney disorders amongst coal cutters of underground mines. *Indoor Built Environ*. 2024;33(6):1003-15. DOI: 10.1177/1420326X241229431.
10. Li J, Yang L, Song T, Qi R. Research on the effects of the high temperature and humidity environment on human comfort in coal mine emergency refuge system. *Safety*. 2019;5(2):28. DOI: 10.3390/safety5020028.
11. Li J, Cai Z, Liu H, Xin Y. Experimental research on the influence of short-term noise exposure on miner's physiology. *Processes*. 2023;11(2):425. DOI: 10.3390/pr11020425.
12. Wang Y, Wang Y, Wang X, Wang C, Li G. Experimental investigation on physiological and perceptual thermal responses through simulated hot-humid deep mine conditions. *Build Environ*. 2024;255:111435. DOI: 10.1016/j.buildenv.2024.111435.
13. Brake DJ, Bates GP. Fatigue in industrial workers under thermal stress on extended shift lengths. *Occup Med*. 2001;51(7):456-63. DOI: 10.1093/occmed/51.7.456.
14. Wang X, Wang Y, Wang Z, Lai X, Sang C. Development and validation of modified predicted heat strain model for various metabolic rates in hot-humid underground environments. *J Therm Biol*. 2025;127:104066. DOI: 10.1016/j.jtherbio.2025.104066.
15. Lai Z, Wang X, Tan H, Huang Y, Lu C. Effect of underground work on cardiovascular system in coal miners. *J Cent South Univ (Med Sci)*. 2015;40(10):1103-8. DOI: 10.11817/j.issn.1672-7347.2015.10.008.
16. Dutta P, Chorsiya V. Thermophysiological vulnerability to heat stress among indoor workers. *Int J Public Health Res*. 2014;1(1):18-24. DOI: 10.17511/ijphr.2014.i1.04.
17. Bartkowiak G, Marszałek A, Dąbrowska A. Thermal load of mine rescuer in the underwear and protective clothing with phase change materials in simulated utility conditions. *Materials (Basel)*. 2020;13(19):4320. DOI: 10.3390/ma13194320.
18. Donoghue AM, Sinclair MJ, Bates GP. Heat exhaustion in a deep underground metalliferous mine. *Occup Environ Med*. 2000;57(3):165-74. DOI: 10.1136/oem.57.3.165.
19. Wu J, Fu M, Tong X, Qin Y. Heat stress evaluation at the working face in hot coal mines using an improved thermophysiological model. *Int J Heat Technol*. 2017;35(1):67-74. DOI: 10.18280/ijht.350109.
20. Obadia PM, Kitenge JP, Kuhangana TC, Verpaele S, Nyongonyi AN, Kitenge TK, et al. Hypoxaemia and risk of asphyxia during underground work in artisanal cobalt mines. *Occup Med (Lond)*. 2024;74(2):178-85. DOI: 10.1093/occmed/kqae008.
21. Ijaz M, Ahmad Sr, Akram M, Mirza K, Carter W. Competitive study of heat-exposed and non-heat-exposed group of workers of underground coal mines, Punjab, Pakistan. Preprint at *Research Square* [Preprint]. 2022. DOI: 10.21203/rs.3.rs-2082288/v1.
22. Ramdhan DH, Ulfa NF, Puspita N, Indriani A. Effect of thermal stress on urine specific gravity, blood pressure, and heartbeat among underground miners. *J Public Health*. 2017;13(2):247-52. DOI: 10.15294/kemas.v13i2.7896.
23. Legault G, Clement A, Kenny GP, Hardcastle S, Keller N. Cognitive consequences of sleep deprivation, shiftwork, and heat exposure for underground miners. *Appl Ergon*. 2017;58:144-50. DOI: 10.1016/j.apergo.2016.06.007.
24. Lutz EA, Reed RJ, Turner D, Littau SR. Occupational heat strain in a hot underground metal mine. *J Occup Environ Med*. 2014;56(4):388-96. DOI: 10.1097/JOM.000000000000107.
25. Ramdhan DH, Indriani NFUA, Puspita N. Effect of heat stress on body weight, blood pressure, and urine specific gravity among underground miners in PT X 2015. The 2nd International Meeting of Public Health 2016 (IMOPH) - Part 1. *KnE Life Sci*. 2018;2018:434-41. DOI: 10.18502/kl.v4i4.2304.
26. Wang M, Shang Y. The relationship between mine environment and hypertension in coal miners. *Chin J Intern Med*. 2008;47(8):661-3. PMID: 19080300.
27. Dey NC, Dey S. Effective utilization of man shift through sustainable workload testing for underground mining machine operators. An ergonomic based man-machine interface approach. *New Trends Prod Eng*. 2019;2(1):394-403. DOI: 10.2478/ntpe-2019-0042.
28. Bo Y, Choo W, Ji L, Huimin L. Physiological responses of people in working faces of deep underground mines. *Int J Min Sci Technol*. 2014;24(5):683-88. DOI: 10.1016/j.ijmst.2014.03.024.
29. Purkait MP, Bhattacharya K. Assessment of physiological health status in relations to different anthropometric and cardio-respiratory measures of head-supported load carrying male porters of Sikkim, India. *Int J Pharm Clin Res*. 2017;9(2):108-13. DOI: 10.25258/ijpcr.v9i2.8291.
30. Zemlyanova MA, Koldibekova YV, Ukhavov VM. The influence of harmful physical factors and industrial dust on changes in some biochemical and functional indicators of the cardiovascular system and respiratory organs in workers engaged in underground ore mining. *Occup Med Ind Ecol*. 2019;11:920-5. DOI: 10.31089/1026-9428-2019-59-11-920-925.
31. Kenny GP, Vierula M, Maté J, Beaulieu F, Hardcastle SG, Reardon F. A field evaluation of the physiological demands of miners in Canada's deep mechanized mines. *J Occup Environ Hyg*. 2012;9(8):491-501. DOI: 10.1080/15459624.2012.693880.
32. Borodavkin DA, Zaytsev AV, Parshakov OS, Khokhryakov DS. Experimental study of working conditions of underground workers in the heating microclimate of a deep polymetallic mine. *Occup Saf Ind*. 2023;2:69-75. (Article in Russian). DOI: 10.24000/0409-2961-2023-2-69-75.
33. Sunkpal M, Roghanchi P, Kocsis KC. A method to protect mine workers in hot and humid environments. *Saf Health Work*. 2017;9(2):149-58. DOI: 10.1016/j.shaw.2017.06.011.
34. Dey NC, Pal S. A look into miners' health in prevailing ambience of underground coal mine environment. *J Inst Eng India Ser D*. 2012;93:37-42. DOI: 10.1007/s40033-012-0004-y.
35. Umeh LO. Geochemical characterization of water resources and associated public health risks in mining areas: A review. *Int J Sci Res Mod Technol*. 2025;4(5):121-31. DOI: 10.38124/ijssrmt.v4i5.546.
36. Batool AI, Naveed NH, Aslam M, da Silva J, Rehman MFU. Coal dust-induced systematic hypoxia and redox imbalance among coal mine workers. *ACS Omega*. 2020;5(43):28204-11. DOI: 10.1021/acsomega.0c03977.

37. Sankaran S, Britto PI, Petchimuthu P, Sushmitha M, Rathinkumar S, Mallaiyan VM, et al. Monitoring of physiological and atmospheric parameters of people working in mining sites using a smart shirt: a review of latest technologies and limitations. In: Chatterjee P, Pamucar D, Yazdani M, Panchal D, editors. Computational Intelligence for Engineering and Management Applications. Lecture Notes in Electrical Engineering, Vol 984. Singapore: Springer; 2023. p. 721-35. DOI: 10.1007/978-981-19-8493-8_53.
38. Dushyantha N, Ilankoon IMSK, Ratnayake NP, Premasiri HMR, Dharmaratne PGR, Abeysinghe AMKB, et al. Recovery potential of rare earth elements (REEs) from the gem mining waste of Sri Lanka: a case study for mine waste management. *Minerals*. 2022;12(11):1411. DOI: 10.3390/min12111411.
39. Ranjan A, Zhao Y, Sahu HB, Misra P. Opportunities and challenges in health sensing for extreme industrial environment: perspectives from underground mines. *IEEE Access*. 2019;7:139181-95. DOI: 10.1109/ACCESS.2019.2941436.
40. Yan L, Yantek D, Lutz T, Yonkey J, Srednicki J. Underground mine refuge alternatives heat mitigation. *J Therm Sci Eng Appl*. 2020;12(2):021019. DOI: 10.1115/1.4044345.