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Prediction of Heat Stress to Mitigate the Occupational Health Hazard in Mines

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Abstract. Explosions, oxygen deficit fatigue, hazardous chemical exposure, radiation, and extreme heat are all very real health hazards in underground mining owing to the confined environment. Deep mine high-temperature heat is one of the most important hazards in coal mining, therefore predicting deep mine underground temperature and subterranean climatic conditions has already become a key safety issue in coal mine operations. Till now, Wet Bulb Temperature is used in Indian coal mining for the measure of heat-stress conditions on humans but it doesn't consider visible and infrared radiation. So, there is a need to use Wet Bulb Globe Temperature (WBGT) for heat stress evaluation. This study attempts to evaluate WBGT and compares with various international standards. Moreover, qualitative heat-associated health disorders (HAHD) is assessed through questionnaire. The finding of the research confirms that the WBGT is above the national institute for occupational safety and health and international organization for standardization standards and mine workers are subjected to HAHD.

Keywords: Occupational health and safety · Deep mine · Radiant heat · Heat stress · WBGT · heat-associated health disorders

1 Introduction

The worldwide population is growing at a faster rate than at any other moment in history, while mineral utilization is increasing more rapidly than population as more consumers join the mineral market and the global quality of living rises [1]. Since minerals are valuable natural resources which serve as key raw materials for core industries, the expansion of the mining sector is critical for a country's overall economic development. And every single one of these businesses requires some sort of fuel to function. Coal is currently among the most important fossil fuels utilised in the globe for power production, steel mills, and other applications. It accounts for 60% and 55% of the energy consumption of the world's two largest coal-producing nations, China and India, respectively [2, 3]. According to an international energy agency (IEA) analysis, fossil fuel consumption in India is expected to hit an all-time peak of 1160 Mt in 2023 (see Fig. 1) [4].

Coal demand remains obstinate, and it is expected to hit an all-time tall this year, increasing global emissions. In the words of the coal ministry, the aim for all Indian coal output for the fiscal year (FY) 2023–24 is 1017 million tonnes (MT), with a forecast of

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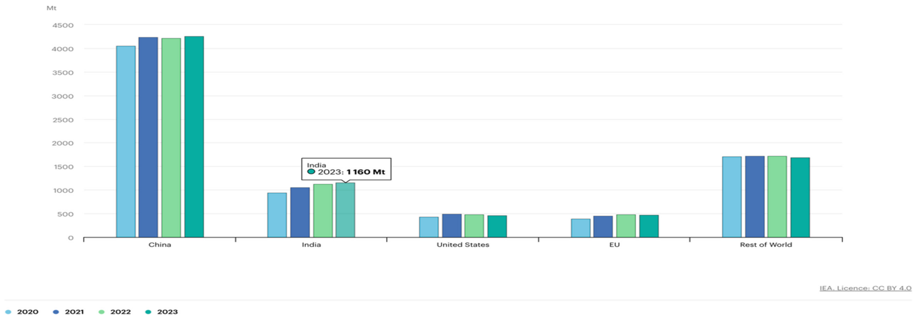

Fig. 1. IEA, Global coal consumption, 2020–2023, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-coal-consumption-2020-2023, IEA. License: CC BY 4.0

1.31 billion tonnes (BT) for FY 2025 and 1.5 BT by FY 2030 [5]. India is now the world's second-biggest coal producer behind China, generating 777.31 million tonnes of coal each year [3]. And the requirement for coal is gradually increasing owing to increased demand in different sectors like electric power generation, steel industries, cement and fertiliser manufacturing, and so on [6]. Underground mines will be operated at deeper depths using high-capacity gear to fulfil demand [7, 8]. Nonetheless, mining operations continue to be relatively people-intensive, making them more prone to disasters caused by human error [9].

With the current emergence of coal output, the employment environment in underground mining has been related to a significant variety of health risk factors, including physically demanding workload, noise, vibration syndrome, exposure to radiation, spontaneous coal heating, and diesel exhaust [10]. Moreover, the high degree of heat, humidity, poisonous gases, and dust in deep mines complicates and makes the underground environment uncomfortable for the miners [11]. As a result, poor environmental factors have an influence on miners' wellness, safety, and production. Underground miners' working ability is diminished owing to health deterioration induced by repetitive and chronic exposure to hot, muggy, and inhalable dust-dominated mining faces. In the underground mining environment, there are several sources of heat, humidity, gases, and so on. Heat stress events are becoming increasingly prevalent in underground mines nowadays. Mine management may take the necessary precautions depending on the extent of heat stress in an underground coal workplace if they are aware of it in advance. Since there are multiple ecological and geotechnical characteristics that might impact an underground mine's heat stress, a little shift in these parameters can result in a significant change in the thermal stress level. As a result, the building of a heat stress prediction method capable of anticipating heat stress for a specific underground mining site is required.

Millions of employees worldwide are subjected to extreme temperatures, strenuous athletic endeavors, and unsafe working conditions that fail to allow for enough rehydration breaks [12]. As underground coal mines get deeper, more extensive, and mined with high-capacity equipment, heat addition from multiple sources such as geothermal gradient, ventilation, and heat expulsion from machinery increases. As a result, heat stress is common in underground coal deposits [6]. The measurement of stress caused by heat in underground mining settings is critical since heat disease is becoming more common as mine depth increases. Researchers have suggested many heat stress indicators to measure the heat stress state in underground mines, but none of them is generally acknowledged [11].

The international standard organization (ISO) 9886:2004 provides measures of body temperature at the core, heart rate, temperature of the skin, and loss of body weight via perspiration for assessing body heat strain. A heat stress indices are one number which incorporates the impacts of the six fundamental variables in any individual's thermal surroundings (such as surrounding temperature, relative humidity, radiation temperature, the velocity of air, metabolic rate, and clothing properties), so that its value differs based on how much thermal stress a person is experiencing [13]. Heat stress is defined as the sum of metabolic heat (heat created in the body) plus ambient heat (heat obtained from the environment) minus heat lost from the human body to the environment. The core body temperature of humans is maintained close to 37 degrees [14]. Heat stress is caused by a combination of environmental factors, the rate of metabolism, and work clothing (Fig. 2) [15]. A working individual generates heat inside the body, notably via muscular effort, contributing to heat stress in an elevated temperature environment [16].

In an underground mine, collecting all of these metrics will become very difficult and time-consuming. Despite the fact that there are several heat stress indices, there has not yet been a clear technique or approach for selecting the appropriate index for a specific subterranean environment [17]. Moreover, an index of one kind cannot function as a "universal index" on its own. A universal indicator would include a range of comfort levels depending on metabolic rates, however, there are numerous heat stress indices that selecting the proper one for a specific sector or work environment may be difficult [17]. As a result, WBGT (Wet Bulb Globe Temperature) measurement is by far the most extensively used and recognised empirical metric for controlling occupational heat stress [18].

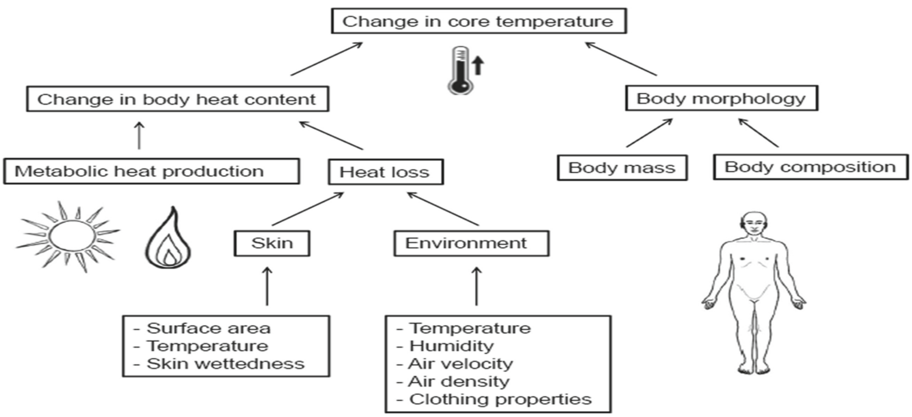

Fig. 2. Biophysical factors affecting the core temperature during exercise and environmental heat exposure. Reprinted from Anatomic Neuroscience, Volume 196, Cramer MN, Jay O. Biophysical aspects of human thermoregulation during heat stress. Pages 3–13 from Els

When sweat evaporation is inadequate and other physiological mechanisms cannot keep the core body temperature from increasing, heat stress leads to temperature-associated occupational disorder, a decline in perceptual function, injuries, and decreased productivity [19]. Heat increases the flow of blood to the skin and causes blood to pool in the legs, which may result in a rapid reduction in arterial pressure [20]. Furthermore, according to 2009 research by Davies, the body's temperature is an autonomous driver of heart rate, increasing it by around 10 beats per minute each degree centigrade [21]. Excessive heat stress may increase the risk of occupational injury owing to fainting, disorientation, poor focus, and psychological discomfort, resulting in decreased protection and dangerous working circumstances [22]. Hot and humid weather may have a substantial influence on underground personnel's performance, overall productivity, and, most importantly, their ability to execute job safely [23]. These circumstances are primarily caused by the presence of gases, a lack of air volume, and excessive humidity, all of which contribute to increased heat stress.

According to the study's findings, there seems to be a higher risk of accidents happening in hot surroundings as contrasted to locations with more moderate temperatures. As a result, it is critical to recognize that when an individual works in a high-temperature setting, not only is their psychological attentiveness lowered, but so is their physical performance. Workers will inevitably become irritated and angry, as well as create other psychological conditions in response to discomfort in their bodies and elevated body temperatures, and these emotional states can end up in the worker ignoring security protocols or doing things that may distract them from potentially hazardous activities.

2 Research Methodology

In order to accomplish the research objectives of this thesis, a well-structured methodology was designed. Firstly, guidelines were framed, based on which the underground coal mines were selected for the field studies. The mine is situated in the Jharia coalfield with a minimum and maximum working depth of 500 m and 650 m respectively. The coal seam is approached through two vertical shafts, one serving as an intake airway and transportation of men and materials, whereas the other is used as a return air shaft and evacuation of coal in skips. Longwall retreating method with a double-ended ranging drum (DERD) shearer for coal cutting is practised in the mine along with Bolter Miner (BM) and Road Header (RH) for the development of panels. The average daily coal production of the mine is 2100 tonnes. It is a degree 3 mine with high methane ($CH4$) emission rate and a sweltering and humid working environment which threatens the health, safety, and productivity of the miners working in the mine. To investigate the effect of the underground mine environment on the health and productivity of the miners, a few miners were randomly selected. The physiological response of those miners was recorded in terms of the questionnaire during shifts to record their true perception of the mining workplace. So, based on the literature review and the response, there needed further field study. Considering the global acceptability and other benefits, WBGT was considered as the heat stress indicator in this research. Leading occupational safety-related bodies, viz. National Institute for Occupational Safety and Health, USA (NIOSH), and Occupational Safety and Health Administration, USA (OSHA), have also

Fig. 3. Heat stress monitor

recommended WBGT as the heat stress index [23]. The parameter that was collected during the field studies includes WBGT which was recorded for the same people who responded to the questionnaire.

In this study, heat stress was measured in terms of the WBGT index. This index cartels the effects of humidity, temperature, air velocity, and radiant heat into a sole digit, which reflects the environmental heat stress condition. WBGT index was measured with the help of a black globe thermometer. This study uses AZ 87784 Heat Stress Meter (Fig. 3) to measure the WBGT index. It measures the WBGT, black globe temperature (TG) and RH% within a range of 0 to 50 °C, 0.1–99.9% RH, and 0 –70 °C respectively. The monitor produced an alarm whenever the WBGT was in the range of 20 –50 °C. Three data were recorded at the workplace and the average was noted. This was repeated for all the locations where miners were performing their tasks.

3 Results and Discussion

For the physiological response of the miners, questions (see Table 1) were developed to investigate the effect of the underground mine environment on the health and productivity of the miners. The questionnaire was sent to various mining, environment and occupational health and safety experts. The responses of the various workers were shown in the Table 2 and the WBGT scale given by different organizations was used to evaluate the Heat stress on miners (see Table 3).

11.11% and 88.88% of the miners were experiencing WBGT between 28 °C to 30 °C and above 30 °C respectively for which NIOSH suggests that the miners should perform light work or should be resting completely. Again, 5.55%, 72.22% and 22.22% of the miners were under the influence of WBGT at 28 °C–30 °C, 30 °C–33 °C and above 33 °C for which ISO 7243 suggests having a metabolic rate of $< 200 W/m^2$, $<130 W/m^2$ and $<65 W/m^2$ respectively. Similarly, 55.55% and 44.44% of the miners were working in a mine environment having WBGT at 28 °C–31 °C and above 31 °C for which rest should be provided often and heavy work should be avoided respectively as suggested by JASA.

Table 1. Heat stress questionnaire

S.No	Questionnaire
1	How would you describe the temperature surrounding you?
2	How often do you sweat at work?
3	Have you ever experienced a red bumpy rash with severe itching?
4	Have you ever experienced Painful cramps in your arms, legs, or stomach that occur suddenly at work or later at home?
5	Have you ever experienced sudden fainting after work and cool moist skin?
6	How often have you experienced heavy sweating, cool and moist skin, tiredness and weakness, and thirst?
7	Have you ever felt weak, confused, upset, have hot dry, and red skin, high pulse, headache, or dizziness in later stages?
8	How often do you experience dry mouth?
9	To what extent are you experiencing stiff muscles or muscle pain?
10	To what extent did fatigue interfere with your physical functioning?
11	To what extent did fatigue interfere with your mental functioning?
12	Have you ever been through guidelines or safety measures to combat heat stress?

3.1 Statistical Analysis

A 5-point Likert scale was used where participants were asked to rate the causes and effects. The numerical data that was gathered was analyzed using SPSS v.25 to generate descriptive statistics. The reliability of the research instrument was measured using Cronbach tests. Cronbach alpha (α) is an important concept in the evaluation of assessments and questionnaires with acceptable values of α, ranging from 0.70 to 0.95 [24]. 15 questions were prepared out of which 3 had fewer values ($\alpha < 0.70$). So, only 12 questions were selected. There was a strong correlation between WBGT and the Perception of heat stress on miners with an R-value of 0.87.

4 Conclusions

In India, WBT has been used for the measurement of Heat stress. So, there is an essence in developing Heat stress standards in Indian Mines using WBGT as it includes the effect of temperature, humidity, wind speed and visible and infrared radiation on miners. Further urine analysis through urine-specific gravity (USG) will provide a better way to understand the effect of heat stress on the miners. It will help the mine management to design the shift duration for working and resting which will reduce the fatigue of miners and lead to better productivity.

Table 2. Response of Heat Stress questionnaire

S.No	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Total
1	5	4	2	3	3	3	2	3	3	3	3	1	35
2	4	4	3	3	3	3	3	3	3	3	3	2	37
3	4	4	3	2	3	3	2	4	4	4	4	2	39
4	3	4	3	4	2	3	3	3	4	2	4	1	36
5	4	5	3	2	3	3	2	3	3	3	3	2	36
6	4	5	3	4	2	4	4	4	4	4	4	1	43
7	4	4	4	3	2	4	3	3	3	4	3	2	39
8	3	5	3	3	3	3	3	4	3	3	3	1	37
9	4	3	2	4	2	4	2	4	4	3	4	2	38
10	4	5	2	4	4	4	4	4	4	4	4	1	44
11	3	4	3	3	3	3	3	4	3	4	4	2	39
12	4	5	2	3	3	3	3	3	4	2	3	1	36
13	3	5	3	3	2	3	3	4	3	2	4	2	37
14	2	5	4	3	3	4	2	2	3	3	3	1	35
15	4	5	3	4	2	4	3	3	4	4	4	2	42
16	4	5	3	3	2	3	3	3	4	4	4	1	39
17	3	4	3	4	3	4	3	4	3	3	3	1	38
18	4	5	3	3	4	3	3	3	4	4	3	2	41

Table 3. Heat stress standards of different organizations.

S. No	WBGT (°C)	HEAT STRESS STANDARDS (WBGT °C)														
		NIOSH					JASA[a]					ISO				
		<25	25	26	28	30	<21	21–25	25–28	28–31	>=31	23	25	28	30	33
S1	29.1				✓					✓				✓		
S2	30.1					✓				✓					✓	
S3	33.7					✓					✓					✓
S4	29.2				✓					✓					✓	
S5	31.3					✓					✓				✓	
S6	34.2					✓					✓					✓
S7	30.4					✓				✓					✓	
S8	31					✓				✓					✓	
S9	30.5					✓				✓					✓	
S10	33.6					✓					✓					✓
S11	30.9					✓				✓					✓	
S12	31.2					✓					✓				✓	
S13	30.7					✓				✓					✓	
S14	31.7					✓					✓				✓	
S15	30.2					✓				✓					✓	
S16	33.3					✓					✓					✓
S17	30.7					✓				✓					✓	
S18	32.7					✓					✓				✓	
Total					2	16				10	8			1	13	4

[a] Japan Sports Association

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Conflict of Interest. No conflict of interest is shown by the authors.

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