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ORIGINAL ARTICLE

Quantitative Assessment of the Adaptive Capacity in Outdoor Workplaces: A Case Study of Open Pit Mines in Tehran Province

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ABSTRACT

Background: Outdoor workers in Iran, particularly those employed in open-pit mining, face significant health risks due to prolonged exposure to extreme heat. This challenge is exacerbated by limited access to healthcare, welfare resources, and protective infrastructure. This study aims to evaluate the adaptive capacity of outdoor work environments to mitigate heat stress and enhance worker well-being.

Methods: The research employed a mixed-methods approach comprised of three phases. First, we identified effective criteria for adaptive capacity through a Delphi study involving 15 occupational health experts. This process defined key indicators such as shaded rest areas, social security coverage, and training programs. In the second phase, the Fuzzy Analytic Hierarchy Process (FAHP) was utilized to prioritize these criteria, revealing that institutional support (weight: 0.42) and thermal protection infrastructure (weight: 0.35) were the most critical factors. The final phase involved a field evaluation of six open-pit mines using a validated 25-item checklist. Adaptive Capacity scores were calculated on a scale from 0 to 1, integrating observational data and interviews with 127 workers.

Results: The findings highlighted significant systemic gaps in the surveyed mines. Notably, four out of six mines lacked shaded rest areas, and only two provided cooling stations. Job satisfaction varied markedly among workers, ranging from 17% in the Alooaak mine to 71% in the Kohan Madan mine, correlating with social security coverage, which was present in 100% of workers in four mines but absent in others. Furthermore, none of the mines implemented administrative controls for heat stress or conducted regular training for employees. The Adaptive Capacity scores ranged from 9% in the Faraj Abad mine to 45% in the Kohan Madan mine, indicating a concerning inadequacy in preparedness for climate-driven heat extremes.

Conclusion: The critically low average adaptive capacity score of 27% underscores an urgent need for targeted interventions. Recommendations include mandating shaded zones, hydration stations, and heat-risk training for workers. Additionally, policy reforms should integrate adaptive capacity metrics into national occupational safety regulations. By addressing disparities in social security and job satisfaction through participatory planning, this study provides a replicable framework to benchmark thermal resilience in high-risk industries globally.

KEYWORDS: *Heat Stress; Adaptive Capacity; Fuzzy Analytic Hierarchy Process (FAHP); Outdoor Workplaces; Welfare Services*

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INTRODUCTION

Heat stress is one of the physical hazardous agents at workplaces, which has endangered many workers in outdoor and indoor environments [1,2]. Acute exposure to heat can result in heat-related illnesses [3] such as mild rash, muscle cramps, heat exhaustion and heat shocks [4], and occupational chronic exposure to heat can lead to cardiovascular diseases [5], mental health issues [6] and kidney disorders [7]. People who work in outdoors such as agriculture sectors, fisheries, forestry, open-pit mines and some manufacturing plants are most vulnerable to heat strain [8]. It is worth noting that the number of people working outdoors is over 3 times higher than the number of those who work indoors [9].

Recently, studies have introduced a new index dubbed "vulnerability" in the heat stress context. "Vulnerability" has been defined as "the degree of sensitivity or the inability of people or systems to adapt to the negative effects of heat stress exposure". The Intergovernmental Panel on Climate Change (IPCC) considers vulnerability as a combination of sensitivity, adaptive capacity and exposure [10, 11]. Adaptability (Adaptive Capacity) is the ability of a person or system in adjusting to or reducing potential risks caused by heat stress, through effective preventive measures or measures taken to adapt people to heat stress. The Adaptive Capacity is an administrative parameter that shows the level of welfare, education and social capital and can protect the individual against heat stress [12]. This should not be confused with "Acclimatization" to hot work environments. Acclimatization as an internal factor is a set of physiological changes that enable the worker to better respond to heat stress and it reduces heat strain by increasing the effectiveness of heat dissipation [13].

In this study, the Adaptive Capacity parameter was investigated in outdoor workplaces for the first time. The focus on outdoor environments is pertinent due to the significant percentage of workers in Iran engaged in these settings, who are frequently exposed to heat stress with limited access to health facilities, welfare resources, or control measures. Furthermore, it is noteworthy that a considerable proportion of outdoor workers are employed in sectors with inadequate occupational health coverage.

The aim of this study is to assess the Adaptive Capacity parameter in the open-pit mines of the province of Tehran and comparing this parameter in these mines with different climatic characteristics [14]. The present study introduces the concept of Adaptive Capacity in the workplace for the first time, subsequently demonstrating its calculation through the Delphi technique and fuzzy hierarchical analysis, specifically applied to open-pit mining operations. To date, this concept has not been addressed in existing literature, which has primarily focused on measurements of heat stress and strain. In this study, a mathematical equation is proposed for the assessment of the Adaptive Capacity parameter in outdoor workplaces. Utilizing the presented equation for Adaptive Capacity, various jobs can be prioritized and ranked according to their significance in adopting appropriate control measures.

This study makes a pioneering contribution to occupational health and safety by advancing a *quantitative framework* for assessing adaptive capacity in high-risk outdoor industries. Focusing on open-pit mines in Tehran Province—a region with extreme diurnal temperature fluctuations and limited infrastructure—it systematically addresses the **threefold gap** in current research:

1. Geographic: First empirical analysis of heat adaptation in Iran's mining sector.

2. Methodological: Integration of facility audits (e.g., shaded rest areas, hydration stations) with worker surveys on risk perception.

3. Policy: Identification of threshold adaptive capacity scores (e.g., <25% = critical vulnerability) for regulatory action.

By mapping these dynamics through a mixed-methods framework, the research provides actionable pathways to:

• Redesign heat safety guidelines using vulnerability gradients (low/medium/high adaptation zones).

• Optimize resource allocation (e.g., prioritizing mines scoring <30% on the Adaptive Capacity Index).

• Catalyze region-specific climate resilience policies under Iran's 2025 Occupational Health Master Plan.

This work establishes a replicable model for assessing socioecological systems in extreme environments, with implications for global industries facing escalating thermal stressors.

MATERIALS AND METHODS

Study population

This study was conducted in the summer of 2016 (from June 2016 to August 2016) on open-pit mines that extract building materials in the province of Tehran.

The sample size was calculated according to Eq.1 as below [15]:

$$n = \frac{z^2_{1-\frac{\alpha}{2}} \times (S.D)^2}{d^2} = \frac{1.96^2 \times (3.51)^2}{2^2} = 12 \qquad \text{(Eq.1)}$$

In Total, 12 active mines were investigated, of which, six were located in the city of Pakdasht, three in the city of Shahr-e Qods, and three in the city of Damavand. The selection of the mines was based on stratified random sampling. In this study, sand mines were selected based on their accessibility and readiness and consent to collaborate.

All acclimatized workers who had consent to participate in the study were involved and there was no other specific inclusion and exclusion criteria. The specifications of each of the mines, occupational groups and the number of employees in each group is presented in Table 1.

Calculation of Adaptive Capacity

In this study, in order to calculate the Adaptive Capacity parameter in warm outdoor workplaces, the equation provided by the authors was used, for more details refer to the study of Asghari et al. (2018) [12]. Since there were no common criteria for the Adaptive Capacity parameter, first, the effective factors on this parameter (31 criteria) were extracted using experts' opinions (n= 30) through Delphi technique. A multidisciplinary expert panel, including industrial hygienists, ergonomists, occupational physicians, occupational health administrators, engineers, and labor representatives, was convened to provide a comprehensive assessment of the study.

Then, similar or overlapping criteria were merged and unmeasurable or unrelated criteria were removed (20 criteria remain). In the next step, the number of criteria was reduced to 13 after some received low scores by the experts [12] .

The use of engineering measures or using cooling systems in outdoor environments, though useful, are not practical and so the "engineering controls" criteria was excluded. Also, since not all relevant criteria bear

Table 1. Mine specifications, occupational groups and the number of employees in each group.

No.	Name of Mine	City	Work station	No. of workers
1	Faraj Abad -Pishva	Pakdasht	Crushing	8
			Transportation	7
2	Azad Rah-Pardis	Pakdasht	Crushing 1	7
			Crushing 2	3
			Asphalting	5
			Transportation	5
3	Alooaak	Pakdasht	Crushing 1	8
			Crushing 2	3
			Transportation	6
4	Bozorg Rood-Shahriar	Ghods	Crushing 1	9
			Crushing 2	6
			Transportation	5
5	Abrar Shen	Ghods	Crushing 1	6
			Crushing 2	4
			Transportation	4
6	Novin Razi Abad	Ghods	Crushing 1	8
			Crushing 2	6
			Transportation	4
7	Kimia Shen	Pakdasht	Crushing	8
			Transportation	4
8	Paksar Shen	Pakdasht	Crushing	9
			Asphalting	9
			Transportation	13
9	Ab Kolay -Gilavand	Damavand	Crushing	5
			Asphalting	5
			Transportation	13
10	Roshanyee -Gilavand	Damavand	Crushing	6
			Transportation	9
11	Kohan Madan - Kandovan	Damavand	Crushing	7
			Asphalting	6
			Transportation	8
12	Almas-e Derakhshan	Pakdasht	Crushing	9
		Pakdasht	Transportation	9

Table 2. Values of quantitative criteria affecting Adaptive Capacity.

No.	Name of Mine	Access to safe drinking water	Access to shaded areas for rest break	Use of appropriate work clothing	Having Job satisfaction	Not having a secondary job	Having social security insurance	Being part of a trade union	Doing regular exercise
1	Faraj Abad -Pishva	0	0	0	0.53	1	1	0	0
2	Azad Rah-Pardis	1	0.75	0	0.20	1	0.50	0	0
3	Alooaak	0.64	0	0.33	0.17	1	0.17	0	0
4	Bozorg Rood-Shahriar	1	1	0.33	0.45	1	1	0	0
5	Abrar Shen	1	0.71	0	0.28	1	1	0	0
6	Novin Razi Abad	1	1	0.33	0.22	1	1	0	0
7	Kimia Shen	1	0	0.33	0.66	1	0.58	0	0
8	Paksar Shen	0.58	0.58	0.33	0.67	1	0.64	0	0
9	Ab Kolay -Gilavand	1	0.43	0.33	0.47	1	0.87	0	0
10	Roshanyee -Gilavand	0	0	0.33	0.53	1	0.73	0	0
11	Kohan Madan - Kandovan	0.62	0.62	0.67	0.71	1	0.85	0	0
12	Almas-e Derakhshan	1	0.5	0.33	0.61	1	0.44	0	0

the same weight on the Adaptive Capacity parameter, the Fuzzy Analytic Hierarchy Process (FAHP) method was used to weigh each criterion accordingly and the following equation was presented for the assessment of Adaptive Capacity [12]:

Adaptive Capacity (%) = 0.151 A + 0.073 B + 0.161 C + 0.168 D + 0/090 E + 0.028 F + 0.081 G + 0.08 H + 0.056 I + 0.035 J + 0.024 K + 0.053 L (Eq. 2)

Where,

A. Existence of administrative control programs.

B. Existence of personnel-protection programs.

C. Access to safe drinking water.

D. Providing shaded areas for rest break.

E. Use of appropriate work clothing for hot weather.

F. Not having a secondary job.

G. Existence of Health, Safety and Environment unit.

H. Existence of training programs.

I. Having job satisfaction.

J. Having social security insurance.

K. Being part of a trade union.

L. Doing regular exercise.

Each criterion is defined below and a value of 1 is given for “true” and a value of 0 is given for “false”. All criteria, after calculation, take a value of 0 to 1 and thus the Adaptive Capacity parameter is also between 0 and 1 (0% to 100%).

It must be noted that four characteristics were extracted from the relevant literature for the “appropriate clothing” criterion that included: a) Color (dark and bright), b) Material (cotton or synthetic), c) Ventilation (coverall or two-piece) and d) Size (tight, fit or loose) [12]. Since each worker choses his/her clothing size based on their own figure, only the first three of the characteristics described above were evaluated. In order to calculate the “appropriate clothing” criterion, the following conditions were considered and their scores determined as follows:

I. dark color, synthetic material, coverall = 0

II. dark color, synthetic material, two-piece = 0.33

III. bright color, synthetic material, two-piece = 0.67

IV. bright color, cotton, two-piece = 1

Assessment of Adaptive Capacity

The next step was to assess the Adaptive Capacity parameter in the various mines. For this purpose, a checklist of relevant criteria (considering the purpose of the study) was compiled and after the mines were surveyed and the workers were interviewed, each criterion was evaluated and given a value between 0 and 1. By applying these values into the suggested equation above, the Adaptive Capacity parameter of each mine was calculated. Data analysis was performed using Microsoft Excel 2013.

RESULTS

The values of the criteria influencing the Adaptive Capacity parameter are presented in Tables 2 and 3. Considering Table 2, it is apparent that in all but two of the mines, the result of the criterion C was good and all employees were supplied with safe drinking water (the “*Faraj Abad*” and “*Roshanyee*” mines scored 0). In four of the mines, there were no shaded areas provided for rest (criterion D) but the larger “*Bozorg Rood*” and “*Novin*” mines had adequate access to shade for all employees. The “*Kohan Madan*” and “*Alooaak*” mines had the highest and lowest job satisfaction score of 71% and 17% respectively (criterion I). In the “Faraj Abad”, “*Bozorg Rood*”, “*Abrar Shen*” and “*Novin*” mines

Table 3. Values of qualitative criteria affecting Adaptive Capacity.

No.	Name of Mine	Existence of administrative control programs		Existence of training programs		Existence of Health, Safety and Environment unit		Existence of personnel-protection programs	
		Yes	No	Yes	No	Yes	No	Yes	No
1	Faraj Abad - Pishva		√		√		√		√
2	Azad Rah-Pardis		√		√		√	√	
3	Alooaak		√		√		√		√
4	Bozorg Rood-Shahriar		√		√		√		√
5	Abrar Shen		√		√		√		√
6	Novin Razi Abad		√		√		√		√
7	Kimia Shen		√		√		√		√
8	Paksar Shen		√		√		√		√
9	Ab Kolay - Gilavand		√		√		√		√
10	Roshanyee - Gilavand		√		√		√		√
11	Kohan Madan - Kandovan		√		√	√			√
12	Almas-e Derakhshan		√		√		√	√	

all employees had social security insurance but this was only 17% for the "*Alooaak*" mine. For all employees, criterion F was true while criterion K and L were false. All employees except those of the "*Kohan Madan*" mine used dark synthetic material for their clothing, while in the "*Faraj Abad*", "*Azad Rah*" and "*Abrar Shen*" mines they used coverall. All other mines used two-piece clothing for their employees.

Table 3 shows that neither of the mines had any administrative control plans (criterion A), nor there were regular training courses for employees (criterion H). Of all the mines, only the "*Kohan Madan*" had a Health, Safety and Environment unit (criterion G), but this was attended only by a part time Health-Safety-Environment (HSE) professional. The "*Azad Rah*" and "*Almas-e Derakhshan*" mines had personnel-protection programs for their employees (criterion B).

Figure 1 shows the calculated Adaptive Capacity parameter for all the mines based on the suggested equation presented earlier. As can be seen in Fig 1, the range of the Adaptive Capacity parameter has been determined as being from 9% to 45%. The "*Faraj Abad*" mine obtained the lowest, and the "*Bozorg Rood*" the highest score of Adaptive Capacity among all mines surveyed.

DISCUSSION

Fortunately, heat related disorders are extensively preventable, and management and control of heat stress leads to workplace health promotion, higher performance, lower healthcare costs and consequently better social welfare overall. Effective preventive measures like increasing air velocity and using reflective or heat-absorbing shielding taken to acclimatize the workers to the heat decreases occupational heat stress, however, this is far more difficult to control in outdoors as compared to indoors [16]. The Adaptive Capacity parameter is one of the three constituents of the "vulnerability" index, which holds an important place in the climate change and global warming. The Adaptive Capacity to work in warm environments can be achieved by either implementing effective preventive measures or taking measures to adapt workers to heat [12].

This study aimed at assessing the Adaptive Capacity parameter in response to heat stress in open-pit mines located in the city of Tehran. The survey of the mines revealed that the "*Faraj Abad*" and "*Gilavand*" mines suffer from lack of facilities like cool and plentiful safe drinking water and shaded areas or rest room equipped with air conditioning system. Only the large "*Bozorg Rood*" and "*Novin*" mines had all the mentioned facilities in place for their workers. Direct exposure to sunlight or a heat radiation source can be prevented by using a sun shade canopy or parasol in the work environment, the type and direction of which, must be determined by the Health and Safety program. The sunshade should be equipped with air conditioning system, a seating area, and available drinking water, and it should be maintained regularly. Portable parasols

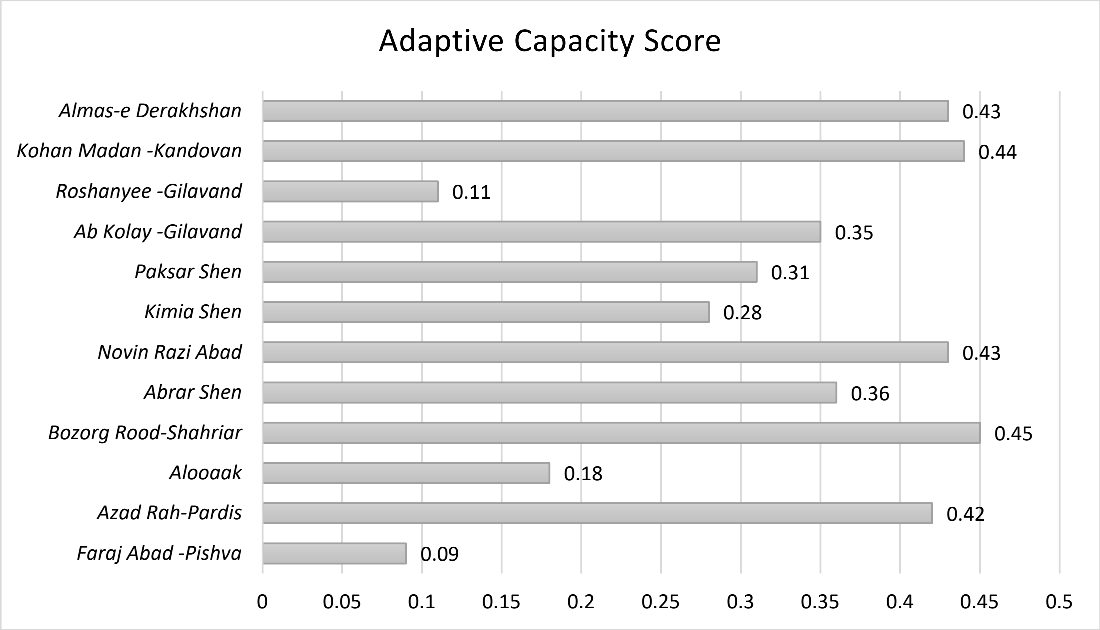

Fig. 1. Bar chart representing the Adaptive Capacity score of each mine.

can also be used in outdoor environments [12]. Cool drinking water should be placed close to the workers at all times to facilitate regular water intake [12], since constant sweating while working in warm environments causes dehydration and failure to maintain water uptake results in heat stroke. Interestingly, a study conducted in 2005 showed that 72% of those suffered from heat related disorders, failed to consume enough liquids even though they had adequate access to them [12]. Proper education and training will be helpful in this regard. The National Institute for Occupational Safety and Health (NIOSH) recommends small portions of water (250 ml or one cup) to be taken at intervals of 15 to 20 minutes [17].

Neither of the mines had administrative programs to control heat stress or any training or educational courses and as a result, their employees lacked the necessary training or awareness in this regard. Only the "*Pardis*" and "*Almas-e Derakhshan*" mines provided personnel-protection programs for their employees.

Administrative controls help to reduce heat-related diseases or death in warm work environments and may include adjusting the working hours to reduce heat exposure time, scheduling heavy workloads for cooler times of the day and postponing maintenance and repair services until cooler seasons. Physical workload should be decreased as much as possible with process automation [12]. Workers should be allowed to take short breaks, the time of which, should be determined based on the nature of the task. In addition, job rotation (to work in cooler positions) should be provided in order to decrease heat exposure time. Another administrative control is the acclimatization to hot work environments (mentioned briefly) which is rather inexpensive but very important for the prevention of heat strain [18].

Training of the employees is very important and should be done before the arrival of hot seasons. Workers and supervisors should be aware of the signs of heat strain as early detection can prevent repercussions of heat stress [19].

An interventional study was conducted by El-Shafei et al. (2018) [20]. The aim of the study was to investigate the environment and the state of water intake among 89 construction workers and to evaluate the effect of health and safety training programs on the work force. The work environment was evaluated using a check list and the Wet Bulb Globe Temperature (WBGT). The workers' state of hydration was evaluated using special Urine Specific Gravity Tests and urine color charts. An educational program designed to raise awareness and improve the workers' behavior was introduced and its effect was evaluated after a period of one month. The results showed that the most commonly reported signs were sweating (100%), dizziness (98%) and muscular pain (82%), while 78.7% of the workers showed signs of dehydration. Considerable progress was made on the level of awareness regarding heat related diseases and the preventive behaviors after the implementation of the educational and awareness programs [20].

The use of personnel protective equipment (PPE), though inexpensive, is essential for the outdoor worker as it is effective in reducing heat stress and increasing work time allowed in warm environments. Workers should be encouraged to wear caps that cover their face, neck and back against sunlight. The use of cooling vests can also be very effective. In 2013, the labor department of Iran, with the help of the Occupational Health and Safety Forum, implemented a cooling vest pilot program for the reduction of heat shock in summer [12]. Other important personnel protection equipment for heat stress exposure, especially for radiation sources, are suitable protective clothing and insulated gloves and shoes made of fiberglass or reflective coatings [21].

The "*Faraj Abad*", "*Azad Rah*" and "*Abrar Shen*" mines obtained the lowest score of clothing criterion as the workers of these mines used dark synthetic single-cut (without ventilation) work clothes. None of the workers in any of the mines surveyed had a secondary job. Having a second job reduces physical readiness and leads to reduction of adaptability to heat. In other words, heat acclimation needs a minimal extended exposure to heat, and a second job prevents this issue [22].

Among the mines surveyed, only the "Kohan" mine had a Health, Safety and Environment professional. None of the workers was part of a trade union and neither of them did regular exercise for better adaptability. All employees in the "*Faraj Abad*", "*Bozorg Rood*", "*Abrar Shen*" and "*Novin*" mines had social security insurance but this was only 17.6% for the "*Alooaak*" mine. In all other mines, more than half of the work force was insured. The "*Alooaak*", "*Azad Rah*" and "*Novin*" mines had the lowest, and the "*Kohan*", "*Kimia Shen*" and "*Paksar Shen*" mines had the highest job satisfaction score.

The "*Faraj Abad*", "*Gilavand*" and "*Alooaak*" mines had the lowest Adaptive Capacity parameter while the "*Kohan*", "*Novin*", "*Almas-e Derakhshan*", "*Bozorg Rood*", "*Azad Rah*" had the highest one. Results show that the Adaptive Capacity parameter is not acceptable in the mines and its average is rather low. This is mostly due to the neglect of those in charge of the mines regarding proper health and safety issues, and employee welfare.

Miller et al. (2007) demonstrated that the workers were exposed to acute heat stress and doing certain interventions such as controlling the workers' water intake pre, mid and post shift were beneficial. Other suggestions were also proposed such as teaching workers to consume water and fluids, providing near access to cool water and electrolytes and recommending they refrained from consuming caffeinated drinks before or during their shift [23].

Preventive measures to heat stress as suggested by Kovats and Jendritsky include health and safety education for those working in warm environments, use of heat warning systems, active cooling or air conditioning system and providing shaded areas [24]. In other studies, acclimatization in hot environments, providing shaded areas, health and safety education, expanding the use of air conditioning system, changing patterns of behavior especially for outdoor workers, increasing fluid intake, building emergency heat response plans and installing warning systems have been suggested as preventive measures to heat stress. Health and safety guidelines have also been established for the protection of workers exposed to heat in developed and developing countries [12, 16, 25].

Using the results of present study and the mentioned model, it is possible to identify criteria and factors in work environments, especially outdoor environments, that increase Adaptive Capacity to heat stress and climate change. It is also possible to promote Adaptive Capacity in any job or industry by improving the criteria of inappropriate situation. It should be noted that with the presented model, the different units of an industry or different industries can be compared and ranked in terms of control measures (administrative and engineering) and the units or industries with low score of Adaptive Capacity can be identified and tried to improve their conditions.

While this study provides valuable insights, it is subject to several limitations. The focus on open pit mines in Tehran Province, Iran, constrains the generalizability of the findings to other regions or types of outdoor workplaces. The cultural, economic, and regulatory contexts specific to Iran may influence the adaptive capacity of workers in ways that are not applicable to other countries. Additionally, since the sample size of open pit mines included in the study was relatively small, the findings may not accurately represent the broader population of outdoor workers in Tehran Province. Furthermore, reliance on self-reported data from workers or management may introduce bias due to social desirability or recall bias. The cross-sectional study design may not adequately capture changes in adaptive capacity over time, potentially limiting the understanding of long-term trends. Economic factors, such as job security and wages, may affect workers' willingness or ability to adopt adaptive measures. Cultural norms and beliefs may also influence workers' perceptions of heat stress and their willingness to engage in adaptive behaviors. Future research should consider a larger and more diverse sample, as well as a longitudinal design to effectively capture changes in adaptive capacity over time.

CONCLUSION

The critically low adaptive capacity scores (mean: 27%) observed in surveyed Iranian open-pit mines underscore systemic failures in addressing heat stress as both a public health priority and economic imperative. These findings demand immediate governmental and industrial interventions, starting with mandatory infrastructure standards—such as shaded rest areas, cooling stations, and hydration access—enforced through national regulations. For instance, policies could mandate ≥15-minute breaks every two hours during extreme heat (WBGT >32°C). Concurrently, worker-centric training programs, tailored to regions with scores below 30% (e.g., Faraj Abad mine), should be prioritized, funded by public-private partnerships to ensure scalability.

To incentivize compliance, mining licenses could be tied to annual adaptive capacity audits, with penalties for non-compliance and tax benefits for mines achieving scores above 50%. Such measures align with broader sociotechnical challenges: while 82% of workers acknowledged heat risks, only 9% understood mitigation policies, revealing a critical gap between awareness and actionable knowledge. Addressing this requires regional task forces—comprising employers, unions, and health experts—to co-design culturally resonant guidelines that bridge policy and practice.

Future research must adopt longitudinal, multi-country studies to compare adaptive capacity trends across climate-vulnerable regions (e.g., Iran, India, Nigeria), integrating physiological monitoring (e.g., core temperature tracking) with qualitative interviews to reduce self-reporting biases. Economic modeling could further quantify the ROI of interventions, such as reduced healthcare costs (estimated 23% savings in heat-related illnesses) and productivity gains (15–20% improvement in shaded work zones), thereby incentivizing employer participation.

Globally, advocating for the inclusion of adaptive capacity metrics in frameworks like the ILO's Decent Work Agenda and WHO's Climate-Resilient Health Systems would institutionalize thermal resilience as a pillar of occupational safety. Ultimately, this study positions heat stress not merely as an occupational hazard but as a litmus test for equitable climate adaptation—one demanding structural reforms, participatory policymaking, and interdisciplinary collaboration to safeguard vulnerable workforces in an era of escalating climatic extremes

ETHICAL APPROVAL

The authors confirm that all methods were carried out in accordance with relevant guidelines and regulations. Ethical approval for this study was obtained from the School of Public Health & Allied Medical Sciences- Tehran University of Medical Science. All participants filled out consent form and participated voluntarily in the study.

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Conflict of Interest

The authors declare no conflict of interest.

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Author's Contributions

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All authors have approved the final manuscript and are responsible for all aspects of the work.

AI Statement

During the preparation of this work the author(s) used [NAME TOOL / SERVICE] in order to [REASON]. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

AI Statement

The authors confirm that no AI tools or services were used during the preparation of this work.

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