LETTER

Heat-health vulnerabilities in the climate change context—comparing risk profiles between indoor and outdoor workers in developing country settings

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Abstract
Oc...
occur when the human body absorbs and generates more heat than dissipated [9]. The core temperature rises quickly when heat gain exceeds heat loss during vigorous physical activity in a warm environment. Although human beings can tolerate a drop in core temperature of 180 °F (100 °C), an increase in core temperature of 90 °F (50 °C) becomes intolerable [9]. Nevertheless, a few million workers work in jobs with chronic high-heat exposures, such as those workers in iron and steel, glass manufacturing, agriculture, mining, military, and construction [10–12]. Workers in such industries have a high tendency to get exposed to scorching environments [12]. Manual work in hot and humid environments imposes considerable health risks [3], reduces productivity [8, 10], and impairs workers’ safety [8, 10, 13]. The heat dissipation mechanism becomes least effective in hot environments due to a reduction in the thermal gradient, whereby skin temperature approaches or exceeds environmental temperature leading to a rise in the Core Body Temperature (CBT), an effect that further compounds if humidity is high, thereby limiting the sweat evaporation and evaporative cooling. Such a response leads to a useless water loss, which may precipitate dehydration and overheat [8].

Workers can have greater vulnerability to heat-health risks depending on their exposures, outdoor or indoor, and other social determinants [14] and disproportionately disadvantaged due to working circumstances and access to cooling provisions and other protective resources. The workplace conditions play a significant role in increasing heat-exposure, sensitivity to heat, sustained workability, and acclimation capacity. In some cases, it may amplify the risks during temperature extremes, thereby increasing their vulnerability to climate-related health effects [4]. Few studies have estimated the heat-related health issues among workers in developing countries [15–17]. No studies have compared the heat-health vulnerabilities between indoor and outdoor workers and have evaluated who is at a higher risk. Understanding the difference in vulnerabilities can help characterize CC impacts and prioritize and develop appropriate interventions or programs to prevent heat stress exposures in the vulnerable worker population. Our objective was to compare the Indoor Organized Workers (IOWs) and Outdoor Unorganized Workers (OUWs) in terms of heat exposure and risks of HRI.

2. Materials and Methods

2.1. Study design, settings and sample size

2.1.1. Sectoral definitions

IOW are defined as registered sectors with the government; employment terms are fixed and are usually covered by workplace insurance [18]. Heat exposures among IOW happen from hot indoor workprocesses, and workers have fixed work targets. OUW are those with no fixed employment terms, and these enterprises are not registered with the government [18]. OUW workers sometimes have fixed targets, and their heat exposures are primarily from direct sun exposure outdoors. There are significant differences in how the workers’ welfare facilities and heat exposures vary between IOW and OUW [18]. In our study, we considered all outdoor sectors as unorganized and indoor sectors as organized.

We used a cross-sectional study design to conduct the study to understand the differences in the workers’ heat-health vulnerabilities between the indoor and outdoor sectors in the CC context in various outdoor (agriculture, construction, brick making, salt pans) and indoor (commercial kitchen, garments, steel & foundry) work sectors spread across the state of Tamil Nadu in Southern India. Taking the 84% prevalence of HRIs from our previous study [15] with 95% confidence and precision of 5%, we derived the sample size of 254 samples using the formula presented by Pourhouseinigholi et al [19]. We used the random cluster sampling technique to recruit 250–260 study participants, a representative sample from each selected occupational sector, with a total sample size of ~2100 to cover the dropouts and lost-to-follow-ups. We sent requests to 28 workplaces, at least three workplaces per occupational sector. We then randomly selected workplaces from the consenting workplaces from each sector to eliminate the selection bias to conduct the study. After obtaining prior ethical clearance from the Institutional Ethics Committee (IEC-NI/17 April 1959/54) and permission from the workplaces, we selected the workplaces with high ambient heat exposures (from heat-generating processes or direct sun exposures) and workers with the manual workload. We explained the risks and benefits of participating in the study to the management and the workers. We obtained signed informed consent from all the workers before initiating the study.

We initiated the study by conducting screening interviews and excluded workers with any reported pre-existing medical conditions like diabetes, hypertension, thyroid illnesses, respiratory diseases, cardiac illnesses, and/or any co-morbidity. We selected workers engaged in moderate to heavy labor in various workplaces between 2013 to 2017, included workers between the ages of 18–70 years working in the same workplace for at least 1 year (figure 1). Data collection was conducted in each workplace for two seasons, summer (April–June), and winter season (November–January) to get the workers’ perception on seasonal heat stress exposure impacts.

2.2. Heat profiling, workload and workplace controls

We profiled the heat exposure by measuring the Wet Bulb Globe Temperature (WBGT), a direct index that reflects the human body’s response to heat stress [20]. The international standard for WBGT uses different
Selection criteria

Inclusion Criteria:
- Age of 18-70 years
- Years of exposure >1 yrs in hot working environments

Exclusion Criteria:
- Using any medication (e.g) NSAIDS
- Any pre-existing medical illnesses (e.g) Diabetes, Hypertension etc.,

Cross Sectional Study design

Sample size N= ~250-260 from each sector
- (OUWS: Agriculture, Bricks, Salt Pan, Construction)
- (IOWS: Commercial Kitchen, Garments, Steel, Foundry)

No of workers N= ~2100

Assessment of heat stress and strain

Quantitative data
- Area heat stress monitoring
  - WBGT
- Physiological monitoring
  - Core Body Temperature
  - Sweat rate
  - Urine Specific Gravity
- Sr. Creatinine for estimating eGFR

Qualitative data
- HOTHAPS Questionnaire
- N= ~2100

Overall statistical Analysis [SPSS version 16.0]

Figure 1. Flow chart of study methodology.
formulas for indoor and outdoor measurements [3] based on three temperature variables: Ta, the air temperature; Tg, the globe temperature; and Tnw, the natural wet bulb temperature representing the impact of evaporation [21]. In this study, we collected WBGT using the 3 M™ QUEST Temp™ 32 heat stress monitor (accuracy of Dry Bulb Temperature/Air Temperature, Wet Bulb Temperature, Globe Temperature, ±0.5 °C; Relative Humidity: ±5%) (Ta,Tnw,Tg, RH) to measure the hourly ambient WBGT during regular shift hours and took an average of the hourly values to have the workers’ representative WBGT exposure in a work-shift. The workers’ work category was judged by a trained Industrial Hygienist based on American Conference of Governmental Industrial Hygienists (ACGIH) guidelines. We categorized the workers in each group (IOW and OUW) into exposed and unexposed using the WBGT permissible ACGIH Threshold Limit Value (TLV) of 27.5 °C for heavy workers and 28 °C for workers with moderate workload [22] to evaluate the risk of heat stress and the corresponding attributed WBGT under which continuous work could be safely undertaken. Information on workplace heat stress controls was collected based on Industrial Hygienists’ observations and workers’ perceptions. We then categorized them as low (no engineering control, but some administrative controls) and medium (some engineering and administrative controls) [23, 24].

2.3. Heat exposures—workers’ perception of health and Productivity Loss (PL)

We collected perception data on heat exposures, health impacts, and PLs by administering a validated High Occupational Temperature Health and Productivity Suppression (HOTHAPS) questionnaire that had fairly detailed questions to elicit information about occupational heat exposure (work duration, timing, and years of exposure), medical history, personal history and experience of HRI symptoms [8]. We explained the HRI symptoms and illnesses clearly to the study participants. We considered the worker to be affected by heat stress if he/she experienced one of the following HRI symptoms, i.e. excessive sweating/thirst, tiredness, cramps, headache, nausea/vomiting, fainting, or prickly heat. Our definition of PL [6] due to heat stress was the self-reported loss in production, or not achieving work targets, or lost work hours and/or wages due to heat or HRI. The perceived PL specific to the season was elicited from the workers using a set of questions.

2.4. Heat stress—health implications

We measured the Heat Strain Indicators (HSIs) viz., Core Body Temperature (CBT), Urine Specific Gravity (USG), and Sweat Rate (SwR) for all 2104 study participants following the standard methodologies and measurement protocols [12, 15]. The measurements of HSI we made pre and post-work for each worker. We measured CBT, using a digital Infra-Red Thermometer (Rossmax), USG, using a refractometer and determined the SwR for each worker and, calculated the SwR using the Canadian sports formula [25]. In this study, we considered HSI as the rise in CBT >1 °C [9, 21], SwR >1 l hr⁻¹ [9, 21], and USGs >1.020 [26]. Due to non-cooperation and other ethical issues associated with collection of blood samples two times within a shift, we collected one blood samples [27] during the first work break of the work shift (mid-way during the shift), to measure serum creatinine to assess acute kidney injury [28] and to calculate estimated Glomerular Filtration Rate (eGFR) (<90 ml min⁻¹/1.73 m²) [29], a marker of reduced kidney function [30, 31], from 969 volunteering workers from all sectors, with exception of garment industries (no permission was granted).

3. Data analysis

We compared the baseline characteristics of indoor as a whole group with the outdoor workers using the chi-square test. Within the group of workers with HRI symptoms and HSI, we also compared the proportion of heat-exposed and unexposed workers between indoor and outdoor workers. For testing the association between the variables, we used the chi-square test with a cut-off of 0.05 for p-values for all analyses. For determining the risk level for exposures and between indoor and outdoor workers, we performed the bivariate analysis Crude Odds Ratio (COR) and Multivariate Logistic Regression (MLR) analysis by taking the presence or absence of exposure within a group (including exposed workers and unexposed workers). We performed three types of MLR analysis using a stepwise method for controlling possible confounders [15]. The Adjusted Odds Ratio (AOR) thus calculated is presented with the corresponding p-values and 95% CIs. We used SPSS-version 16 for statistical analysis and Origin pro (2020b, learning edition) for graphs.

4. Results

4.1. Descriptive analyses

We evaluated a total of eight-workplaces and interviewed 2506 workers for preliminary screening. After excluding about 8.4% of workers based on the inclusion/exclusion criteria, we had a total study population of 2104, outdoor (N = 1053, 50.1%), and indoor (N = 1051, 49.9%). Table 1 shows the descriptive characteristics of the study population in both groups in South India. The outdoor workers were significantly older than the indoor workers (mean difference 6.3 years, median difference 5 years). The proportion of male workers (61.4%) was higher than female workers (38.5%) with literacy level significantly higher among IOW (80%). Although most of the study participants were non-smokers and non-alcoholics, the proportion of smokers (n = 308,
14.6%) and alcoholics (n = 417, 19.8%) were higher among OUW. Manual work with heavy workload was significantly higher among OUW (86.7%) compared to (51.1%) the IOW (p < 0.001) (table 1).

Figure 2 shows the workplace WBGT °C exposures of workers among the IO and OU sectors. Among the outdoor sectors, agricultural workers had maximum WBGT exposures (37.5 °C) and steelworkers (49 °C) among the indoor workers. The heat exposures exceeded the TLV for safe manual work for moderate/heavy work both in the outdoor (Avg. WBGT of 29.1 ± 2.4 °C) and indoor (Avg. WBGT of 29.8 ± 3.9 °C) workplaces. 74.4% (N = 784) OUW and 68.7% (N = 723) IOW were exposed WBGTs greater than TLV limits, and exposures were much higher in summer than winter.
WBGTs beyond 30 °C were observed in select sectors; both indoor and outdoor (figure 2). Although the heat exposures were high in both sectors, OUW had significant heat exposures (OR: 1.3; p < 0.004). Among the indoor group, very high radiant heat and WBGTs were measured in steel and foundries, and the workers had average WBGT heat exposures of >30.0 °C for the most part of the year.

Table 2 represents the distribution of various variables among indoor and outdoor workers, clearly showing a significant difference for self-reported HRI symptoms and PLs, measured HSI, such as CBT, SwR, USG, and kidney function between the sectors. The levels of heat stress control in the workplaces were also significantly different between the sectors.

4.2. Risks of HRI/HSI/reduced kidney function/PLs
The bivariate analysis demonstrates increased risks for outdoor workers for almost all variables (table 3). OUW reported significantly higher HRI symptoms and PL than IOW (90.3% vs 78.3%, p < 0.001), except for urogenital issues. Irrespective of the sector, the heat-exposed workers had experienced at least one of the urogenital issues. We find similar trends for measured HSI (figure 3), and the proportion of HSI among the OUW was significantly higher than the IOW (table 3). The odds of prevalence of HRI symptoms, HSI, and PL were significantly higher among the OUW. Although the bivariate results were attenuated in multivariate analyses, the tendencies remained the same for both the models, ‘A’ after adjusting effect modifiers such as age and gender, ‘B’ for confounders such as education, smoking, alcohol, and years of heat exposure, and ‘C’ for adjusting both the effect modifiers and confounders. The OUW had 2.1-fold higher odds of reporting HRI symptoms that were significantly associated. Model C shows a 1.5-fold increased risk of the urogenital issue and ∼11.4-fold higher odds of reporting PLs by the OUW. Although HSI’s risk diminished from Model A to B, there remained significant risks of all measured HSI for OUW (table 3). Stratified analysis by age, gender, and work category (table 3), shows that exposed workers >40 years had a significantly higher risk of HRI symptoms (AOR: 1.8; p < 0.001), female workers had a 1.4-fold higher risk than males, and exposed workers with heavy workload had a 1.7-fold higher risk than workers with the moderate workload. The odds of reporting HRI symptoms in summer was significantly higher among the OUW compared to the IOW in all the models (table 3).

Table 4 illustrates the comparative analyses (bivariate and multivariate) of the heat-exposed workers (above TLV levels for the work category) between the IOW and OUW. Our results clearly show that OUWs had a 2.8-fold increased odds of reporting HRI symptoms after adjusting for all confounders than the IOWs. OUWs had significantly higher share of heat stress exposures during summer (AOR: 1.6) even after adjusting for all confounders (table 4). The risk of dehydration, changes in urine volume and
Table 3. Comparison of self-reported HRIs symptoms and measured HSI indicators between OUW (N = 1053) and IOW (N= 1051) workers using logistic regression models in South India.

| Study variables | Bivariate ORf (95% CI); p-valueg | Multivariate A ORf (95% CI); p-valueg | Multivariate B ORf (95% CI); p-valueg | Multivariate C ORf (95% CI); p-valueg |
|-----------------|---------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|
|                 |                                  |                                        |                                        |                                        |
| Age             |                                 |                                        |                                        |                                        |
| >40 yrs         | 2.7 (1.82–4.03); <0.001          | 2.8 (1.90–4.24); 0.031                 | −1.7 (1.04–2.74); 0.013               | 1.8 (1.13–3.03); 0.013                |
| <40 yrs         | 1.2 (0.87–1.65); 0.247           | 1.2 (0.90–1.70); 0.08                 | 0.8 (0.54–1.14); 0.211               | 0.9 (0.60–1.28); 0.523               |
| Gender          |                                 |                                        |                                        |                                        |
| Male            | 1.6 (1.14–2.09); 0.004           | 1.5 (1.12–2.06); 0.559               | 1.1 (0.78–1.58); 0.593               | 1.1 (0.77–1.56); 0.593               |
| Female          | 2.1 (1.37–3.34); 0.001           | 2.1 (1.37–3.33); 0.213               | 1.4 (0.82–2.43); 0.210               | 1.4 (0.82–2.44); 0.210               |
| Worker category |                                 |                                        |                                        |                                        |
| Heavy           | 2.4 (1.75–3.18); 0.001           | 2.3 (1.71–3.14); 0.010               | 1.6 (1.11–2.20); 0.02               | 1.7 (1.24–2.52); 0.03                |
| Moderate        | 1.1 (0.64–1.64); 0.899           | 0.9 (0.61–1.59); 0.157               | 0.6 (0.35–1.18); 0.18               | 0.6 (0.33–1.11); 0.19               |
| Season          |                                 |                                        |                                        |                                        |
| Summer          | 2.6 (1.85–3.90); 0.001           | 2.3 (1.57–3.44); 0.19                | 2.7 (1.84–4.23); 0.21                | 2.2 (1.46–3.45); 0.22                |
| Winter          | 2.1 (1.46–2.94); 0.001           | 1.9 (1.38–2.80); <0.001              | 2.3 (1.58–3.24); <0.001             | 2.1 (1.45–3.02); <0.001             |

Self-reported heat stress symptoms:

| Heat stress symptoms (any one) | Indoor | Outdoor | Bivariate ORf (95% CI); p-valueg | Multivariate ORf (95% CI); p-valueg |
|-------------------------------|--------|---------|---------------------------------|------------------------------------|
| Indoor                        | 2.6 (2.00–3.32); <0.001 | 2.3 (1.80–3.03); <0.001 | 2.5 (1.88–3.20); <0.001 | 2.1 (1.60–2.77); <0.001 |
| Outdoor                       |        |         |                                 |                                     |
| Workload                      | 6.2 (5.05–7.77); <0.001 | 16.1 (12.05–21.66); <0.001 | 6.9 (5.48–8.72); <0.001 | 16.7 (12.4–22.6); <0.001 |
| Dehydration                   | 1.6 (1.38–1.97); <0.001 | 1.8 (1.47–2.13); <0.001 | 1.8 (1.48–1.16); <0.001 | 1.8 (1.48–2.18); <0.001 |
| Change in urine volume/color   | 2.7 (2.26–3.25); <0.001 | 2.3 (1.94–2.81); <0.001 | 1.7 (1.4–2.17); <0.001 | 1.6 (1.31–2.07); <0.001 |
| Urino-genital issues           | 2.1 (1.37–3.12); <0.001 | 1.9 (1.29–3.03); 0.002 | 1.5 (0.93–2.26); 0.095 | 1.5 (0.95–2.73); 0.082 |
| PL                             | 11.7 (7.76–17.8); <0.001 | 10.8 (7.12–16.48); <0.001 | 13.1 (8.58–20.24); <0.001 | 11.4 (7.39–17.6); <0.001 |

Rise in CBT (<1 °C, >1 °C):

| Rise in CBT | Indoor | Outdoor | Bivariate ORf (95% CI); p-valueg | Multivariate ORf (95% CI); p-valueg |
|-------------|--------|---------|---------------------------------|------------------------------------|
| Indoor      | 1.9 (1.45–2.40); <0.001 | 2.1 (1.57–2.65); <0.001 | 1.9 (1.49–2.56); <0.001 | 2.1 (1.60–2.79); <0.001 |

(Continued.)
Table 3. (Continued.)

| Study variables | Bivariate OR \(^{f}\) (95% CI); \(p\)-value\(^{e}\) | Multivariate A OR \(^{f}\) (95% CI); \(p\)-value\(^{e}\) | Multivariate B OR \(^{f}\) (95% CI); \(p\)-value\(^{e}\) | Multivariate C OR \(^{f}\) (95% CI); \(p\)-value\(^{e}\) |
|-----------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
| SwR (<1 hr\(^{-1}\), <1 hr\(^{-1}\)) | | | | |
| Indoor | | | | |
| Outdoor | 2.4 (1.93–3.03), 0.001 | 2.7 (2.16–3.45), <0.001 | 2.0 (1.58–2.55), <0.001 | 2.4 (1.83–3.02), <0.001 |
| USG (<1.020, >1.020) | | | | |
| Indoor | 1.3 (1.04–1.58), <0.001 | 1.3 (1.03–1.61), 0.021 | 1.3 (1.10–1.70), 0.005 | 1.4 (1.08–1.71), 0.009 |
| Outdoor | 1.3 (1.04–1.58), <0.001 | 1.3 (1.03–1.61), 0.021 | 1.3 (1.10–1.70), 0.005 | 1.4 (1.08–1.71), 0.009 |
| Measured HSIs (any one) | | | | |
| Indoor | | | | |
| Outdoor | 2.4 (1.47–3.98), <0.001 | 2.3 (1.35–3.78), 0.002 | 1.7 (1.02–2.88), 0.042 | 1.7 (1.00–2.93), 0.049 |

\(^{a}\) Model multivariate A adjusted for effect modifiers.
\(^{b}\) Adjusted for gender only.
\(^{c}\) Adjusted for age only; model multivariate B for confounders such as smoking, alcohol, education, years of exposure, season; model multivariate C corrects for both effect modifiers and confounders.
\(^{d}\) Model multivariate A (effect modifiers) corrects for age, gender; model multivariate B (confounders) corrects for education, smoking, alcohol, years of exposure, season.
\(^{e}\) \(p\)-value < 0.05 is significant.
\(^{f}\) More than one denotes the presence of risk.
\(^{g}\) For seasonal comparison, the models excluded season as a cofounder.

\(^{#}\) Denotes that it is the reference group.

Figure 3. Comparing the distribution of workers with measured HSI among indoor and outdoor workers in South India (\(n = 2104\)).

The results of this South Indian cross-sectional study demonstrate various risks for developing HRI for outdoor vs indoor workers, irrespective of age, gender, education, smoking, and alcoholism. OUWs are at increased risks of physiological heat strain and HRIs and risk of reduced kidney function compared to IOWs (table 5). Workers in indoor sectors also had heat and workload risks but had a different risk profile than the IOW concerning welfare facilities and heat stress prevention controls. The OUWs
Table 4. Logistic regression models comparing various variables between heat-exposed (above TLV) indoor organized vs OUWs in South India (N = 1507).

| Study variables | Bivariate ORb (95% CI); p-valuea | Multivariate A ORb (95% CI); p-valuea | Multivariate B ORb (95% CI); p-valuea | Multivariate C ORb (95% CI); p-valuea |
|-----------------|---------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| **Self-reported HRI symptoms** |                                 |                                      |                                      |                                      |
| **Heat stress symptoms (any one)** |                                 |                                      |                                      |                                      |
| Indoor Outdoor  | 3.4 (2.45–4.71); <0.001         | 2.9 (2.06–4.06); <0.001              | 3.3 (2.36–4.78); <0.001              | 2.8 (1.92–4.00); <0.001              |
| Workload       | Indoor Outdoor 6.2 (4.73–8.26); <0.001 | 18.1 (12.4–26.43); <0.001              | 8.2 (6.05–11.28); <0.001              | 21.4 (14.42–31.9); <0.001              |
| **Season**c     | Indoor 1 Outdoor 2.1 (1.67–2.71); <0.001 | 1.9 (1.50–2.49); <0.001              | 1.9 (1.46–2.53); <0.001              | 1.6 (1.22–2.24); <0.001              |
| Dehydration     | Indoor Outdoor 1.6 (1.32–2.01); <0.001 | 2.1 (1.52–3.01); <0.001              | 1.7 (1.40–2.23); <0.001              | 1.7 (1.38–2.25); <0.001              |
| Change in urine volume/color | Indoor Outdoor 2.9 (2.41–3.71); <0.001 | 2.4 (1.96–3.09); <0.001              | 1.8 (1.4–2.4); <0.001               | 1.7 (1.30–2.29); <0.001              |
| PL              | Indoor Outdoor 9.3 (5.93–14.76); <0.001 | 8.4 (5.29–13.40); <0.001              | 11.6 (7.08–19.1); <0.001             | 8.6 (5.26–14.26); <0.001              |
| **Measured HSI symptoms** |                                 |                                      |                                      |                                      |
| Rise in CBT (<1 °C, >1 °C) | Indoor Outdoor 2.2 (1.59–2.94); <0.001 | 2.4 (1.79–3.39); <0.001              | 2.23 (1.60–3.11); <0.001            | 2.5 (1.8–3.64); <0.001              |
| SwR (>1 l hr⁻¹, <1 l hr⁻¹) | Indoor Outdoor 2.2 (1.67–2.76); <0.001 | 2.4 (1.88–3.19); <0.001              | 1.7 (1.35–2.32); <0.001             | 2.1 (1.55–2.78); <0.001              |
| USG (<1.020, >1.020) | Indoor Outdoor 0.9 (0.70–1.16); 0.425 | 0.8 (0.67–1.15); 0.369                | 0.86 (0.66–1.14); 0.314             | 0.8 (0.63–1.13); 0.270              |

Model multivariate A (effect modifiers) corrects for age, gender. Model multivariate B (confounders) corrects for smoking, alcohol, education, years of exposure; season; model multivariate C corrects for both effect modifiers and confounders.

a p-value < 0.05 is significant.
b More than one denotes the presence of risk.
c For seasonal comparison, the models excluded season as a cofounder.

had lower literacy levels (20%) and, their awareness and understanding of heat protection were minimal, which could be attributed to the higher prevalence of HRIs in outdoor sectors [15]. In both the groups, heat levels were high, especially in summer, and exceeded the TLV levels for safe work limits [22]. Heavy work intensity was almost twice as much among the OUWs than the IOWs, a proven risk factor for HRIs [15, 17]. Organized sectors had higher mechanization/automation that reduces work intensity and consequent heat stress risks [8] and has better welfare facilities, including cooling provisions and sanitation access [5].

Outdoor workers had direct sun and >TLVs exposures [22]. However, indoor sectors with high-heat generating processes such as in steel/foundry had chronic WBGT exposures >30 °C (figure 2). Our findings show that higher proportions of OUW
and Indoor Heat-exposed (above TLV) indoor vs outdoor workers (N = 713)

| Study variables                  | Bivariate OR (95% CI); p-value | Multivariate A OR (95% CI); p-value | Multivariate B OR (95% CI); p-value | Multivariate C OR (95% CI); p-value |
|----------------------------------|--------------------------------|------------------------------------|------------------------------------|------------------------------------|
| Indoor vs outdoor workers (N = 969) |                                |                                    |                                    |                                    |
| Indoor                           | 1                              |                                    |                                    |                                    |
| Outdoor                          | 1.4 (1.10–1.84), 0.007          | 1.2 (0.89–1.55), 0.230             | 1.2 (0.89–1.57), 0.245             | 0.9 (0.69–1.29), 0.739             |
| Heat-exposed (above TLV) indoor vs outdoor workers (N = 516) |                                |                                    |                                    |                                    |
| Indoor                           | 1                              |                                    |                                    |                                    |
| Outdoor                          | 1.4 (1.03–1.88), 0.028          | 1.1 (0.78–1.51), 0.611             | 1.2 (0.81–1.61), 0.432             | 0.8 (0.53–1.15), 0.222             |

Model multivariate A (effect modifiers) corrects for age, gender. Model multivariate B (confounders) corrects for smoking, alcohol, education, years of exposure, season; model multivariate C corrects for both effect modifiers and confounders.

More than one denotes the presence of risk; indicator of reduced kidney function is eGFR.

The risk of dehydration, was statistical significance for all the models after adjusting for potential confounders (table 4). A high level of dehydration and HRI prevalent among OUsWs indicates insufficient hydration and a lack of heat stress management practices at workplaces [10, 40], corroborated by the workers’ self-reported HRI symptoms [15]. The hot and humid climate that prevails for 6–8 months of the year in southern India [12] further adds to the heat burden, which will further deter the workers’ health and productivity now [13] and in the future, especially with the predicted temperature rise [14, 46]. The prevalence of indicators of reduced kidney function (N = 969) among OUsW (27.6%, N = 268) was higher compared to IOW (16.8%, N = 163) (table 5). Kidney stones and CKD associated with high-heat exposures in indoor [12] and outdoor work settings [11, 32, 37]. The reduced renal health symptoms for IOW in our study could be credited to the workers from the high-heat industries such as steel and foundries [12] working near furnaces wearing aluminum overalls had a higher risk of kidney stones [6, 12, 47]. The combination of heavy workload and above TLV-WBGT exposures are the key drivers for adverse kidney function [17, 48]. In our study, we could not see any significant differences in the prevalence of reduced kidney function between summer and winter among the OUW and IOW, though it was reported earlier [49].

Our study results show that IOWs with heavy workloads are at higher risk of having higher serum creatinine and eGFR <90 ml min⁻¹/1.73 m² compared to indoor workers with similar exposures (table 5). This is in concurrence with the previous findings [48] and could be attributed to workers’ literacy levels experienced HRI symptoms compared to the IOWs (tables 3 and 4). The risk of heat exposures (table 3) and HRI symptoms (table 4) were higher during summer among the OUsWs compared to the IOWs, highlighting the significant influence of season on the disease development [4]. Dehydration, in turn, further increases HRI and HSI risk among workers, particularly among those exposed to high ambient temperatures and intense physical activity [4, 5]. Although the proportion of the workers with elevated USG was not largely different between the groups (14.3% vs 10.4%), there was a significant risk of elevated USG for OUsWs. Various studies show that USG increases with decreased body mass due to sweat loss induced by heat and heavy physical activity [32–36].

The higher prevalence of measured HSI among the heat-exposed OUsWs (table 4) has been reported earlier [5], and chronic occupational heat exposures are associated with adverse long-term health effects such as cardiovascular diseases, mental health problems, and Chronic Kidney Disease (CKD) [37]. The combined effect of heat and heavy workload subjects the workers to dehydraion, HRIs, and reduced productivities, especially when sweat evaporation is insufficient and other physiological changes cannot prevent the CBT from rising [17, 38–41]. This is the case with the OUsW in developing nations with limited mechanization that heavily relies on manual labor [15, 17, 41–42]. Our study results concurred with reports of occupational heat strain associated with dehydration and increased USG [5, 6, 10, 44]. Under specific conditions, heat strain occurs in IOW with high-heat exposures and heavy workload, especially if they are wearing semi-permeable or impermeable personal protective equipment [6, 45].
[48] that contribute to the lack of awareness about the risks of heat stress and related behavior, and low level of heat stress controls in OUW [50]. It could be suggested that OUWs are more vulnerable to the ill-effects of heat stress as they are less likely to receive appropriate heat mitigation, protection, or compensation for loss of production. Although both the groups were exposed to excessive heat levels in the current study, outdoor work in a hot climate imposes high-heat stress risks due to strenuous work and solar radiation [10, 15, 16]. The huge potential risk of heat-related injury and accident may be disguised by the underestimated number of HRIs and death [51, 52] in exposed workers in both groups. Thus, heat-protection and mitigation policies must consider both the organized and unorganized work sectors [4, 5, 15, 53].

For a fast-growing economy like India, the risk of heat stress on occupational health and productivity is high [54]. There is a 10.7-fold higher risk of PL among OUWs than IOWs even after adjusting for potential confounders (table 3—model C). Core temperature elevation and dehydration have adverse effects such as physical fatigue, lethargy, impaired judgment and vigilance decrement, coordination, and concentration in the job, potentially leading to compromised business outcomes [10, 52]. PLs were reported most commonly among outdoor/semi-outdoor occupations with high workloads [4, 15]. While in organized sectors, control measures including cooling interventions, job rotation, and better welfare facilities are in place with reasonably protective regulations, the workers in unorganized outdoor sectors lack these protective interventions [4, 5, 15]. OUWs deserve more protection via labor policies and require training on workplace heat stress risks, especially in recognizing early symptoms of heat strain before it proceeds too far, to protect themselves [55]. This does not diminish the need for protective measures and adaptation strategies for the indoor workers exerting in high-heat work environments.

Being the first study to compare the vulnerability between IOW and OUW exposed to occupational heat exposures in Indian occupational settings, the study’s strengths are the large sample size in field conditions with equal representation from indoor and outdoor groups. Our results have self-reported HRIs and also have quantitative HSI measurements to further corroborate the workers’ perceptions. Our major limitation was that data on other factors that influence HRI, including dietary, genetic, and other exposure factors, could not be collected due to the limited project scope and budget. The study could be conducted only in consenting workplaces that could have introduced an unavoidable sampling bias. Quantitative measures of PL could not be collected to corroborate the self-reported PL. Considering the narrow spread of sector selection in our study, caution should be exercised regarding the generalization of the results.

Within the study’s limitations, the findings concur with other studies that have also shown associations between high-heat exposures and health implications and adds to the accruing scientific evidence on the increased risk of workplace heat stress on the health and productivity of the workers [4, 5, 10, 15, 17], an important step to feed into important preventive policy implications for millions of workers in developing countries with tropical climates.

In conclusion, OUW, particularly those with chronic heat exposure outdoors and work condition exposures that are not protective, are more vulnerable than the IOW. The health risks of heat are higher among these workers due to lack of proper infrastructure, workers’ risk-prone behavior (especially when working for piece-rate pay) [56], lack of workplace regulations such as duration of work, and improper work/rest schedule practices and appropriate welfare facilities [57]. This group deserves more protection from the management, employers, and government by providing feasible and sustainable Occupational Safety and Health practices, including training, protective workplace policies, and cooling interventions. Our results also highlight the need for proactive action, failing which the outdoor workers in unorganized sectors will be further pushed to health and economic disabilities [58–61] in the light of CC.

6. Conclusions

Our study demonstrates a strong correlation between heat exposures, workload, and HRIs and HSIs with consequent and adverse health outcomes among heat-exposed workers. In conclusion, OUWs, particularly those with long years of chronic heat exposures, especially when exposed to work conditions that are not protective, are more vulnerable to risks of HRIs and PLs than indoor workers. Lack of workplace controls, including automation and insufficient literacy levels among the OUWs, make them significantly vulnerable to adverse effects of heat stress exposures. The climate predictions warrant urgent intervention and adaptation strategies with a holistic approach while at the same time also encouraging and ensuring mitigation actions at a regional and national level. Evidence-based research and intervention are needed to drive comprehensive protective labor policies to prevent the occupational health and productivity risk consequences for a few million workers in developing countries in the looming climate crisis.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.
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