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Occupational heat stress induced health impacts: A cross-sectional study from South Indian working population

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Abstract

Rising temperature and heat stress risks in the changing climate scenario might potentially affect workers globally, especially the ones with strenuous workload in tropical settings. We used a cross-sectional study design to profile the heat exposures of ~1900 workers from eight industrial sectors using a QuesTemp Wet Bulb Globe Temperature (WBGT) monitor, quantified select heat-strain indicators viz., rise in Core Body Temperature, Sweat Rate, and Urine Specific Gravity and evaluated the perceived health impacts of heat stress using a structured questionnaire. Heat exposures (average WBGT: 30.1 ± 2.6 °C) exceeded the Threshold Limit Value for 67% workers and was positively associated with the rise in Core Body Temperature >1 °C in 13% and elevated Urine Specific Gravity >1.020 in 9% workers. Heat-related health concerns were reported by 86% workers, and the heat-exposed workers had 2.3 times higher odds of adverse health outcomes compared to unexposed workers ($p < 0.0001$). Exposure to higher WBGT and adverse renal health among salt-pan workers were significantly associated ($p = 0.004$), and steel workers had 9% prevalence of kidney stones. Evidence presented clearly points to heat stress as a health and productivity risk factor that could have long-term and irreversible health impacts. In-depth assessments are urgently needed to develop scientifically sound preventative interventions and protective labor policies to avert the adverse occupational health and productivity consequences for millions of workers globally, thereby aiding poverty reduction.

Keywords: Climate change; Occupational heat stress; Physiological heat strain; Renal issues; Dehydration; Workload

1. Introduction

Temperature rise by at least 1.5 °C with predicted increasing frequency and intensity of heat waves is an expected adverse consequence of climate change around the globe in the coming decades (IPCC, 2018; Baldwin et al., 2019). Though the enhanced heat exposures in the climate change scenario is likely to adversely impact the health, wealth, and economy of the poor and low-income countries around the world, the adverse effect of the heatwaves is predicted to impact the outdoor working population to a largest extent (Kjellstrom, 2016). India has been classified as one of the vulnerable regions exposed to extreme weather risks in the global climate risk index (Kreft et al., 2016) with predicted heat-induced economic losses due to decreased health and fatalities (Kenny et al., 2017; Kjellstrom et al., 2014; Mitchell et al., 2019). The southern region has high-heat conditions for the most part of the year with climatic fluctuations (Ramachandran et al., 2017) that have a considerable influence on the indoor workplace temperatures (Wagner et al., 2007). Heat-generated from the processes indoor also influences the workplace temperatures, and this, combined with lack of ventilation precipitates into undesirable health outcomes and

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productivity outcomes (Krishnamurthy et al., 2017; Methner and Eisenberg, 2018; Nag et al., 2009; Xiang et al., 2014).

Global warming and occupational heat stress have been previously linked to respiratory, cardiac, and kidney diseases among working people due to elevated workplace temperatures (Kjellstrom and Hogstedt, 2009). Heat stress causes sweat and dehydration with subsequent volume depletion, which, if progresses, may cause acute kidney injury (Johnson, 2016; Peraza et al., 2012). The incidence of heat-related diseases, related dehydration, renal diseases, both acute and chronic, are estimated to rise with the predicted increase in the frequency and intensity of heatwaves (Hansen et al., 2008; Knowlton et al., 2009). Workforce with physically exerting jobs in hot work environments, both indoor and outdoor, have chronic direct thermal injury that can cause kidney tissue damage leading to repetitive Acute Kidney Injury (AKI), kidney stones, adrenal damage (Gonzalez-Quiroz et al., 2018; Krishnamurthy et al., 2017; Tanthanuch et al., 2005). Chronic Kidney Disease of Unknown Cause (CKDu), attributed to heat has reached epidemic proportions in select working communities in Central America, India, etc. (Johnson et al., 2019) is currently being reported in other parts of the world too (Venuthurupalli et al., 2018; Wanigasuriya et al., 2011).

Occupational heat stress has been associated with the doctor-diagnosed kidney disease observed in a large cohort study in South East Asia that recommended immediate occupational health interventions for workers exposed to heat stress for most part of the year especially in the tropical climates (Tawatsupa et al., 2012). Without sound prevention strategies in place, this epidemic may accelerate due to temperature rise in the global warming scenario (Glaser et al., 2016). Designing comprehensive protective labor policies coupled with scientifically sound workplace interventions are urgently needed to avert health risks for a few million workers across the globe, especially in the developing nations with hot climates. With this background, the present study aimed to study the impact and magnanimity of occupational heat stress impacts on the health of the workforce in southern India.

2. Methodology

2.1. Study design and study population

We conducted a cross-sectional study in about 35 workplaces in eight work sectors spread across southern India and central India. We obtained the ethics clearance from the Institutional Ethics Committee (IEC) and took prior approval from the workplaces to conduct the study (Table 1). We conducted an initial walk-through for selecting and recruiting the workplaces from the various occupational sectors in about 50 workplaces, of which 35 workplaces were found to be suitable and were willing to participate in the study. The workplaces were located in Chennai, Villupuram, Nagapattinam, Tiruchirappalli, Tiruvannamalai districts in the state of Tamilnadu, Bengaluru in Karnataka state and Mumbai city in the state of Maharashtra. Data collection was conducted in each workplace for two seasons, once during the hotter season (April−June) and another during the cooler season (November−January) between the years 2013−2019.

We conducted a preliminary screening to recruit workers between the age of 18−60 years with heat exposures at the same workplace for at least six months. From the screened participants, we excluded the workers who had a pre-existing medical condition like diabetes and hypertension. Based on their willingness to participate, we obtained informed consent from the workers and collected data on the worker's heat exposures, their perception of heat stress, heat strain symptoms, and self-reported health impacts.

2.2. Assessment of heat stress, physiological strain and workers' perception of health

We made qualitative assessments using a structured High Occupational Temperature Health and Productivity Suppression (HOTHAPS) questionnaire to obtain their perceptions on heat stress impacts on their health and heat strain symptoms. Most of the workers could speak and understand English or the local language spoken by the interviewer, or we translated the questions for some migrant workers from other states. The questionnaire had 25 sections that elicited information about the demographic characteristics, their work pattern, fluid intake pattern, toileting practices, heat-related health symptoms, adverse kidney symptoms, sickness/absenteeism due to heat illnesses, productivity losses etc. We explained the symptoms of heat strain clearly to each participant before the responses were elicited and we used excessive sweating, thirst, tiredness, cramps, headache, nausea/vomiting, fainting, or prickly heat/rashes as heat strain symptoms.

Table 1
Distribution of workers' characteristics in various occupational sectors ($n = 1842$).

	Sector/Industry	No. of workers	Age >40 (persons (%))	Male/Female (%)	Smoking (persons (%))	Alcohol (persons (%))
Outdoor ($n = 1094$)	Agriculture	325	193 (59.4)	31.1/69.9	41 (12.6)	64 (19.7)
	Construction	288	44 (15.3)	92.7/7.3	63 (21.9)	91 (31.6)
	salt-pan	276	205 (74.3)	55.4/34.6	75 (27.2)	104 (37.7)
	Brick	205	81 (39.5)	58.0/42.0	41 (20.0)	48 (23.4)
Indoor ($n = 748$)	Auto-parts	66	29 (43.9)	100.0/0.0	15 (22.7)	23 (34.8)
	Foundry	104	1 (1.0)	100.0/0.0	12 (11.5)	8 (7.7)
	Garments	130	30 (23.1)	14.6/85.4	6 (4.6)	10 (7.7)
	Steel	448	180 (40.2)	79.9/21.1	46 (10.3)	58 (12.9)

We obtained quantitative data on heat stress using a calibrated portable heat stress Wet Bulb Globe Temperature (WBGT) monitor (QuesTemp°34), QUEST Technologies, USA which had an accuracy level of ±0.5 °C between 0 °C and 120 °C of dry bulb temperature and ±5% relative humidity. We usually did the assessments as per the protocols recommended by (NIOSH, 2016) during the regular shift hours (9.00 am−3.00 pm) in most workplaces, except in salt pans, brick kilns, and select agricultural workplaces depending on when the work starts. We used the WBGT permissible heat exposure Threshold Limit Value (TLV) to evaluate the risk of heat stress and the corresponding WBGT under which continuous work during an hour could be safely undertaken (ACGIH, 2018; Krishnamurthy et al., 2017).

For consenting workers, we measured physiological heat strain indicators viz., rise in Core Body Temperature (CBT) using an infrared thermometer, Urine Specific Gravity (USG) measured using a refractometer (Venugopal et al., 2016c) and Sweat Rate (SwR) was calculated using the formula of Canadian Sports Association (Parsons, 2014). The CBT and SwR were measured for 1361 workers. However, in some out-door sectors, we could only collect 723 urine samples, due to practical difficulties pertaining to the women workers. In order to study and better understand the impacts of chronic high-heat exposures on renal health, we selected one out door informal sector (salt-pan industry) and one indoor formal sector (steel industry) in which workers had high heat exposures for most part of the year. We tested blood serum creatinine of workers for estimating the Glomerular Filtration Rate (eGFR), an indicator of kidney function (Caplin et al., 2017) in the steel industry. Based on the self-reported symptoms, clinical history and recommendations of the occupational health specialist, we subjected ~91 workers in the steel industry to a kidney ultrasound scan for diagnosing prescence of any renal calculi and other kidney-related anomalies.

2.3. Data analysis

All data analysis was done using Microsoft Excel 2007 and R-statistical software. We conducted a bi-variate analysis for identifying associations using the chi-square test. We present Crude Odds Ratios (COR) as the measure of association, and a cut-off of 0.05 is used to interpret the significance of the p-values for all analyses. Multivariate logistic regression analysis using a stepwise method is used for controlling possible confounders. The Adjusted Odds Ratio (AOR) thus calculated is presented with the corresponding p-values and 95% Confidence Intervals (CI).

3. Results

3.1. Study population and demographics

We evaluated a total of 35 workplaces in about eight sectors and selected 1842 workers after conducting a preliminary screening with 1990 workers. We excluded 8% of the workers from the study as they reported having one of the pre-existing medical conditions such as diabetes and/or hypertension. Of the total study population, 64% (n = 1187) were males and 35% (n = 655) were females (Table 1) with a mean age of 36.8 ± 12.6 years. Approximately 67% (n = 1242) of the participants had primary education. Eighty-four percent were non-smokers, 22% consumed alcohol and about half of the study population had more than five years of heat exposures, and were working in the same industry.

3.2. Heat stress profile

The WBGT levels ranged between 21.2 and 41.7 °C in the various sectors assessed, and a majority of the workers had jobs with heavy workloads (67%) followed by 33% of workers with moderate workload (Table 2). Among the 1842 workers, nearly 85% had WBGT exposures above the TLV limits for the various work intensity categories. We present the average environmental exposures from the various work sectors in Table 2, alongwith self-reported heat strain symptoms (percentage of workers who reported experiencing any one of the heat strain symptoms mentioned in Section 2.2), and illustrate the WBGT profiles in Fig.1 which clearly show that though the maximum percentage of participants were working above safe limit in salt-pan industry, the maximum WBGTs exposure to the workers was observed in the steel industry. A significant association between heat stress and work intensity was observed ($p < 0.0001$). As can be seen from Table 2, the heat stress levels were quite high in the salt pan, steel, and agricultural sectors.

3.3. Workers' perception of heat stress impacts on health

The workers' perception on the impacts of heat stress and experiencing heat strain symptoms were collected through direct interviews using HOTHAPS questionnaire and about 85% (n = 1564) of the workers reported experiencing any one of the heat strain symptoms such as excessive sweating, thirst, tiredness, cramps, headache, nausea/vomiting, fainting or prickly heat/rashes. Workers with heat exposures above the TLVs (85%) perceived experiencing heat-related health symptoms that were significantly associated ($p = 0.0001$), as compared to workers exposed to WBGTs below TLVs (Table 3). The odds of reporting heat-related health symptoms was 2.3 times higher among workers exposed to heat stress higher than the TLV levels in the respective work categories compared to workers who had heat exposures below TLV even after adjusting for confounders like age, gender, education, and type of sector ($p < 0.0001$). As far as experiencing heat strain symptoms, male workers (predominantly with the heavy workload) reported more heat-related health symptoms compared to their female counterparts ($p = 0.0001$). Among the workers with different workloads, workers engaged with heavy workloads had 1.6 times higher risk of reporting more heat-related health symptoms (67%) compared to workers with moderate workloads ($p < 0.0001$).

Table 2
Heat Stress profiles and distribution of workers exceeding American Conference of Governmental Industrial Hygienists (ACGIH) recommended TLVs for various work intensities and self-reported heat-related health symptoms from various occupational sectors in southern India (n = 1842).

Sectors (No. of participants)	Environmental exposures					Work intensity & workers' exceeding the TLV limits[a] (persons (%))		Self-reported heat strain symptoms (persons (%))
	Avg. ambient		WBGT (°C)			Heavy	Moderate	
	Dry bulb (°C)	Relative humidity (%)	Min	Max	Avg. ± SD			
Agriculture (325)	31.3	51.5	20.4	37.5	28.4 ± 2.5	185 (56)	34 (10)	301 (93)
Construction (288)	34.1	46.5	22.1	35.0	27.7 ± 2.5	99 (34)	63 (22)	253 (88)
Salt pan (276)	30.9	54.2	26.5	33.3	30.1 ± 1.2	255 (92)	11 (4)	262 (95)
Brick (205)	33.8	32.9	22.9	35.0	27.7 ± 2.6	84 (41)	12 (6)	179 (87)
Auto-parts (66)	39.2	39.5	22.9	36.4	29.3 ± 3.0	43 (65)	ND[b]	52 (79)
Foundry (104)	31.5	50.1	22.2	31.0	27.9 ± 1.8	73 (70)	ND	97 (93)
Garment (130)	34.5	47.6	23.2	33.1	27.1 ± 2.3	66 (51)	ND	126 (97)
Steel (448)	33.1	52.2	20.1	41.7	29.6 ± 3.8	261 (58)	67 (15)	294 (66)

Note: [a]Average ambient parameters during the time of workplace heat measurements; [b]ND: Not determined.

3.4. Heat strain responses and health symptom

The physiological responses indicative of heat strain such as CBT, SwR, and USG measured with the participants while working are given in Table 4 for the various work sectors indicate that the heat strain symptoms are higher among the workers employed in high-heat environments, notably in the salt-pan and steel industries. High levels of symptoms of dehydration was prevalent in all sectors (>75% of the workers in each sector), but was found to be the highest among the foundry workers (100%) and salt pan workers (99%). Construction, agriculture, foundry and steel worker reported higher percentages of urogenital issues compared to other sectors (Table 4). As can be seen from Table 5, the level of heat exposures had a direct bearing on the physiological strain experienced by the workers. The workers with exposures to higher heat loads (>30 °C) had the highest risk of physiological strain (OR = 2.7; $p < 0.0001$) compared to workers with moderate heat strain (27.5−30.0 °C). Adverse heat-related health symptoms were higher among workers with heavy workload compared to workers with moderate workload (OR = 3.3; $p < 0.0001$). Workers with very high heat exposures combined with physical exertion had 3.6 times higher risk of physiological strain such as CBT, SwR and/or USG (a proxy indicator for dehydration) even after adjusting for confounders ($p < 0.0001$) (Table 5). The blood serum creatinine levels of the workers from salt pans were significantly associated with their WBGT exposures, and the workers exposed to higher WBGTs had 2.9 times higher risk of decreased kidney function as indicated by their eGFR values ($p = 0.05$). The ultrasound results of the steel worker showed renal calculi in about 9% of the workers who had high heat exposures ($p < 0.0001$) (Table 6).

Table 3
Association between workers' heat exposure, self-reported symptoms of heat stress and other demographic variables for the study population (n = 1842).

Variables	p-value[a]	Adj. ORs[b]	95 %CI
Self-reported heat stress symptoms			
1 = Yes	<0.0001	2.3[c]	1.78−3.023
2 = No[d]			
Age			
>40 years	0.003	1.16	0.932−1.435
<40 years[d]			
Gender			
Male	0.086	–	–
Female[d]			
Education			
Illiterate	0.0001	0.661	0.525−0.833
Literate[d]			
Smoking/Alcohol			
Yes	0.038	0.710	0.577−0.904
No[d]			
Workload			
Heavy	<0.0001	1.6[e]	1.285−1.969
Moderate[d]			
Sectors			
Organized[d]	0.904	–	–
Unorganized			

Note: [a] p-value < 0.05 is significant; [b] More than 1 denotes the presence of risk; [c]Adjusted for work category, education, alcohol consumption and years of exposure; [d] Reference group; [e] Adjusted for alcohol, smoking and years of exposure.

4. Discussion

4.1. Heat stress profile and workers' perception

Heat conditions in many work sectors exceeded the TLVs and WBGT exposures of about 85% of the workers exceeded the recommended heat TLVs for the observed work intensity. The workers in indoor workplaces with higher TLVs had exposures from high-heat generating processes that included furnaces/ovens or they were exposed to direct sun, if they were outdoor workers, such as in agriculture, steel, foundry, construction, salt pans, and brick manufacturing (Fig. 1). Our results show that though outdoor sun exposures were high, especially during summer, the heat exposures in many indoor workplaces with high-heat generating processes and limited or no ventilation had higher WBGTs than the recorded outdoor

Table 4
Physiological heat strain symptoms/indicators (self-reported and measured) in various work sectors among workers exposed to occupational heat stress ($n = 1361$, unit: persons (%)).

Sectors (No. of participants)	Number of workers exposed to heat levels above TLV[a]	Quantitatively measured heat strain indicators			Self-reported health symptoms		
		Rise in CBT >1 °C[b]	SwR[c] above safe limit >11 h^{-1}	Rise in USG[d]	Heat stress symptoms[e]	Dehydration	Urogenital issues
Agriculture ($n = 223$)	155	13 (8)	6 (4)	5 (8)	149 (96)	206 (92)	72 (46)
Construction ($n = 112$)	72	21 (29)	7 (10)	3 (11)	66 (91)	109 (97)	34 (47)
Salt-pan ($n = 232$)	224	37 (17)	44 (19)	34 (15)	216 (96)	230 (99)	34 (15)
Brick ($n = 109$)	44	20 (45)	19 (43)	1 (2)	43 (98)	108 (89)	4 (8)
Auto-parts ($n = 66$)	43	3 (7)	4 (9)	nil[f]	39 (90)	48 (72)	4 (9.3)
Foundry ($n = 62$)	43	1 (2)	8 (19)	27 (63)	43 (100)	62 (100)	15 (35)
Garments ($n = 128$)	64	1 (1)	nil	nil	64 (100)	124 (96)	13 (20)
Steel ($n = 429$)	310	45 (15)	26 (8)	22 (7)	214 (69)	378 (88)	142 (46)

Note: [a]ACGIH standard, 2018; [b]Dehghan et al., 2012; [c]Parsons, 2014; [d]Montazer et al., 2013; [e]Percentage of workers who gave an affirmative response for experiencing any one of the heat strain symptoms such as excessive sweating, thirst, tiredness, cramps, headache, nausea/vomiting, fainting or prickly heat/rashes; [f]nil: no data was taken for quantifying the specific parameter.

Table 5
Logistic regression model of occupational heat stress-induced physiological strain and health impacts in the study population ($n = 1361$).

	Variables	Physiological strain (persons (%))	COR[a]	AOR[a]	95% CI	p-value[b]
Levels of exposure	No exposure WBGT ≤ 27.5 °C (reference group)	83 (6)	1.0	1.0	−	−
	Medium-heat exposure ($n = 832$) 27.5 °C < WBGT ≤ 30.0 °C	132 (16)	1.74	−	−	0.001
	High-heat exposure WBGT > 30 °C	216 (23)	2.7	−	−	<0.0001
Work category	Heavy vs. moderate for workers exposed to WBGT > 27.5 °C ($n = 955$)	348 (36)	3.8	3.6[c]	2.44−5.57	<0.0001
Measured heat strain indicators	CBT	187 (14)	1.356	−	−	−
	SwR	141 (10)	1.903	1.8[d]	1.144−2.757	0.010
	USG	197 (27)	2.91	−	−	−

Note: [a]More than 1 denotes the presence of risk; [b]p-value < 0.05 is significant; [c]Adjusted for age, gender, alcohol, smoking and years of exposure; [d]Adjusted for years of exposure.

ambient temperatures during the sampling period. Lack of ventilation, limited cooling provisions and poor welfare facilities seen not only in many indoor informal workplaces but also large formal industries that resulted in elevated heat levels inside the workplaces which is very common (Nag et al., 2009; Krishnamurthy et al., 2017; Venugopal et al., 2016a). With an large economy like in India that is anticipated to grow even

Table 6
Association between WBGT exposures and measured adverse kidney symptoms in salt-pan and steel industry workers.

Sub-set population	Measured adverse kidney symptoms (persons (%))	Crude OR[a]	Adjusted OR[a]	95% CI	p-value[b]
Salt-pan workers[c] ($n = 232$)	120 (51)*	2.9	2.81	1.02−7.73	0.04
Steel workers[d] ($n = 340$)	30 (8.8)*	0.320	0.015	0.123−0.836	0.017

Note: [a]More than 1 denotes the presence of risk; [b]p-value < 0.05 is significant; [c]Adverse kidney symptom in defined by eGFR value; [d] Referral to occupational health specialist after self-reported adverse kidney symptoms; * Overall % prevalence in the study population.

faster in the coming decades (Sanders, 2015), the risk due to work-related heat stress on the occupational health and productivity is high (Fig. 1). The self-reported perceptions of the workers also corroborate this observation as workers from almost all workplaces perceived that occupational heat stress had negative implications on their health (Table 3). Such high-risk hot working environments have been reported not only in India (Lundgren-Kownacki et al., 2018; Nag et al., 2009; Venugopal et al., 2016a, 2016b) but also around the globe (Alimohamadi et al., 2012; Crowe et al., 2010; Tawatsupa et al., 2013). Heavy workload, lack of automation, and limited cooling intervention exacerbate this heat for workers that have been previously reported (Nag, 2001; Venugopal et al., 2016a), which is also observed from the workers' perceptions in this study (Table 3). The study results add further evidence along with other Indian based studies (Nag et al., 2009; Krishnamurthy et al., 2017; Venugopal et al., 2017) to the fact that even modest increase in global temperature, as predicted with climate change will potentially increase the workers' heat exposures that is likely to have significant implications on the workers' health and productivity in India and other similar tropical countries where workers already have

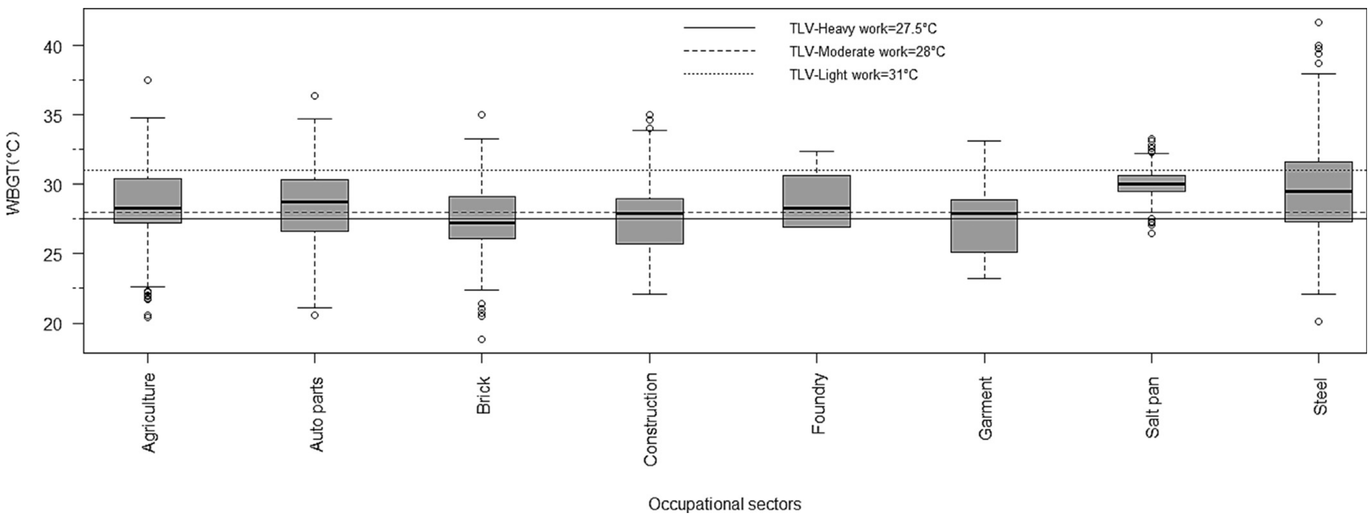

Fig. 1. Average yearly (2013−2017) heat stress exposures (attributed WBGT (°C)) profiles in various occupational sectors.

exposures to excessively high heat levels (Kjellstrom et al., 2009).

4.2. Heat-induced physiological strain and health impacts

Human responses to excessive heat are usually manifested by physiological indicators such as a rise in CBT, SwR, and USG, if not controlled has consequent health risks that are well established (Parsons, 2014). The results of the measured heat strain indicators among workers (32%) especially SwR was significantly associated with the level of heat exposure (AOR = 1.8; 95% CI: 144−2.757; p = 0.010) as was evidenced in previous studies (Chinnadurai and Venugopal, 2016; Venugopal et al., 2016a, 2017; Manjunath et al., 2018). A share of 92% of workers reported symptoms of physiological strain such as excessive sweating and tiredness/weakness (n = 1265), a natural consequence of heat exposures, and heavy workload. The high prevalence of elevated USG values in about 27% (n = 197) workers indicates excessive sweating and consequent dehydration that increases heat strain (Sawka et al., 2001) and also indicates workers' behavioural modifications in fluid intake and urinating pattern (Venugopal et al., 2016c) that increases the risk of heat-related illnesses (Rooney et al., 1998; Casa, 1999; Aragón-Vargas et al., 2009). The combined effect of heat and heavy workload subjects the workers to a higher risk of heat-related health illnesses (COR = 2.5; $p < 0.0001$; 95% CI: 1.783−3.023) that has also been reported in our previous studies (Venugopal et al., 2016a, 2016b; 2016c, 2017; Krishnamurthy et al., 2017) and by other researchers (Akerman et al., 2016; Kjellström et al., 2014; Lucas et al., 2015; Wesseling et al., 2014).

An increase in the prevalence of kidney diseases in populations living in hot, humid climates (Raju et al., 2014) and prolonged exposures can produce a range of heat-related health effects including exhaustion, fatigue, muscle cramps, rashes, prickly heat and/or kidney anomalies (Crowe et al., 2015; Mac et al., 2017; Nerbass et al., 2017; Jayasekara et al., 2019). Upon exposure to hot, humid conditions and strenuous work, an individual's core temperature rises and produces excessive amounts of sweat to lose the internal heat produced to maintain the thermal balance via evaporative cooling (Sawka and Young, 2006). Repetitive severe dehydration is commonly associated with 'pre-renal' dysfunction, acute kidney injury and might potentially cause, rhabdomyolysis, and hypotension that may lead to low-grade renal injury that could progress to Chronic Kidney Disease over time (Nerbass et al., 2017). About 9% of workers had renal calculi in the steel industry, of which 67% of the workers were from the high-heat zones of the industry with chronic exposures to WBGT > 30 °C and this could be attributed to the imbalance in blood osmolarity caused by intensified kidney function while exercising in a warm environment and insufficient fluid intake (Vander et al., 2001). Such high incidence of renal calculi among select working communities with causalities being imbalanced fluid intake, sweating, and repetitive dehydration (Butler-Dawson et al., 2019; Jayasekara et al., 2019). Our finding is also supported by the high prevalence of reduced kidney function and CKD in agricultural communities in hot and humid work settings (Wegman et al., 2018; Wesseling et al., 2016). High prevalence of nephrolithiasis among workers toiling in high-heat environments like in glass factories and foundries are caused due to heat, recurrent dehydration, and strenuous work (Atan et al., 2005; Borghi et al., 1993; Clark et al., 2016). Results similar to our study was also observed among Brazilian metal workers exposed to very high temperatures (45 °C or more) suffered from high kidney stone prevalence (~10%) compared to only 0.009% prevalence in workers who worked at room temperatures (Atan et al., 2005). Immediate health and productivity risks of heat exposure and dehydration are well-established factors that increase the risk of decreased/compromised renal health (Brooks et al., 2012). An in-depth scientific understanding of the linkage between occupational heat stress and related health effects will potentially contribute to the risk-reduction by strategizing appropriate and feasible interventions including automation and improving workers' welfare facilities, an essential aspect of safe work practices.

5. Conclusions

A strong correlation between heat exposures, workload, and physiological strain indicators was observed in this study, demonstrates that high occupational heat exposures cause adverse health outcomes among the exposed workforce. Prevalence of a high level of dehydration among the workers indicates insufficient fluid in-take behaviour, poor welfare facilities, and lack of heat stress management practices in the workplace. The following are the main results of the study.

1) Heat exposures exceeded the TLV for 67% workers for their work categories;
2) Core Body Temperature > 1 °C in 13% and elevated Urine Specific Gravity > 1.020 in 9% workers clearly indicate heat strain prevalence among workers;
3) Heat-related health concerns were reported by 86% workers and the exposed workers had 2.3 times higher risk of adverse health outcomes compared to unexposed workers;
4) Exposure to higher WBGT and adverse renal health among salt-pan workers were significantly associated ($p = 0.04$), and steel workers had 9% prevalence of kidney stones.

The results are of concern as the predicted temperature rise due to global warming will further enhance the heat situation in the already hot work environments with a consequent increase in exposures and adverse health impacts on workers. Interventions that are scientifically sound, cost-effective, feasible, and with a holistic approach are urgently needed to address the heat stress situation at workplaces, while at the same time also ensuring climate change mitigation actions. Evidence-based research and epidemiological assessments in different workplaces and geographical locations with a seasonal approach are imperative to drive comprehensive protective labour policies and workplace welfare facilities to avert the adverse risks of occupational heat stress on health and productivity for millions of workers globally to tackle the looming climate crisis.

Declaration of Competing Interest

The authors declare no conflict of interest.

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