Original Article

Investigating the Impact of Heat Exposure Among Agricultural Communities in a CKDu Hotspot

Vidhya Venugopal[1], **Balaji Gummidi**[2], **Rekha Shanmugam**[1], **Dillip Kumar**[3], **PK Latha**[1], **R Balakrishnan**[1], **K Kailasam**[1], **Oommen John**[3], **Vivekanand Jha**[2,3,4]

[1]Department of Environmental Health Engineering, Sri Ramachandra Institute of Higher Education and Research, Chennai, Tamil Nadu, [2]Prasanna School of Public Health, Manipal Academy of Higher Education, Manipal, India, [3]School of Public Health, Imperial College, London, [4]George Institute for Global Health, UNSW, New Delhi, India

***Corresponding author:** Vidhya Venugopal, Department of Environmental Health Engineering, Sri Ramachandra Institute of Higher Education and Research, Porur, Chennai, Tamil Nadu, India. E-mail: vvidhya@ehe.org.in*

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Abstract

Background: The rise in global temperature poses significant health risks, particularly for those working outdoor in hot weather. This study examines the impact of heat exposure on working people in Uddanam, Andhra Pradesh, India, known for its high chronic kidney disease (CKD) prevalence. **Materials and Methods:** This cross-sectional study assessed heat exposure in 596 participants in various occupations in 36 Uddanam villages. Wet bulb globe temperature (WBGT) assessed heat exposures alongside heat stress perception and health impacts during cooler and hotter seasons. A subset was tested for blood and urine to assess kidney function. **Results:** Participants were mostly males (60.1%) with a median age of 42 years. Among them, 49% were illiterate, 26% smokers, and 41% consumed alcohol. WBGT values were 31.7±2.2°C and 25.5±2.5°C in the hotter and cooler seasons, respectively. Occupational heat exposure varied significantly, with agriculture, brick kiln, and construction workers experiencing highest WBGT exposures. WBGT-Threshold limit values were exceeded by 16.7% and 100% workers in cooler vs. hotter seasons, respectively. Most (98.5%) had excessive heat exposure, reporting 5.7 times more heat-related symptoms. Heat stress index cross-shift changes were greater in heat-exposed participants (OR: 2.4; 95% CI: 1.6–3.5). Among 266 individuals, 76% had eGFR <90mL/min/1.73m^2, with heat-exposed workers showing increased risk (OR 2.1, 95% CI: 1.1–3.7). **Conclusion:** This study shows the health consequences of heat exposure in workers from CKDu hotspots like Uddanam, and the necessity for targeted heat stress mitigation and kidney health protection strategies. Further research is needed to determine the causal links between heat exposure and CKDu progression.

Keywords: *Dehydration, Heat strain, Heavy workload, Occupational heat stress, Reduced kidney function*

Introduction

Climate change has emerged as a pressing global challenge, with far-reaching implications for human societies and ecosystems. Among its numerous consequences, increasing temperatures and heat waves have drawn attention due to their adverse effects on human health. As anthropogenic greenhouse gas emissions continue to escalate, the warming trend shows no signs of abating, leading to concerns regarding the impacts of ambient heat, especially on vulnerable populations. Particularly, agricultural workers, who are highly exposed to the changing environmental conditions, are susceptible to detrimental consequences.

Exposure to high ambient heat can lead to several health problems, including dehydration, heat stress, exhaustion, and stroke. These detrimental health effects are particularly worrisome in individuals with pre-existing health conditions.

Dehydration reduces blood flow to the kidneys, causing concentrated urine with reduced volume, darkened color, and a burning sensation during micturition.[1] Severe hyperthermia-induced volume depletion can lead to acute kidney injury (AKI). Repeated episodes of AKI can lead to irreversible, progressive kidney function loss or chronic kidney disease (CKD). CKD is one of the fastest-growing non-communicable diseases worldwide, with a particularly rapid increase in low and lower-middle-income countries.

Population clusters with higher than usual CKD prevalence have been reported in many parts of the world. This CKD of

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unknown origin (CKDu) is mostly encountered in rural agricultural communities. One such region is the coastal district of Srikakulam, Andhra Pradesh, India, known as Uddanam. The age and sex-adjusted CKD prevalence in this area is estimated at 18-22%, which is 2.5 to 3.3 times higher than the population CKD prevalence reported from other Indian regions.

Although the exact reason for the CKDu development is unknown, prolonged exposure to excessive heat stress combined with a heavy workload has been postulated as one risk factor,[2] especially among those working long hours in hot temperatures.[3] Other postulated mechanisms include exposure to environmental contaminants like pesticides and silica.

Given that Andhra Pradesh has experienced repeated heat waves for 4-5 years, evaluating its effect on outdoor workers, with an emphasis on kidney function, provides a unique opportunity to understand if heat exposure is responsible for the high CKD burden in this region.

We conducted this preliminary study to assess ambient heat exposure's impact on the working population's health. We examined seasonal variations in heat exposure and their impact on kidney health among various Uddanam communities.

Materials and Methods

The cross-sectional study was conducted in 36 villages across six mandals (administrative units) in Uddanam after obtaining approval from the Institutional Ethics Committee of the George Institute for Global Health (IEC Ref no: P01009). The study was conducted per the guidelines of the Declaration of Helsinki for human studies. Prior approval was taken from the workplaces. Data were collected during the cooler (November 2020 - January 2021) and hotter seasons (September 2021 - October 2021 and May 2022 - June 2022) during the regular workday (8:00 am to 5:00 pm) [Supplementary File A].

The study included 18–75-year-olds who had worked at least six months. Patients with diabetes or hypertension were excluded. The workers' heat exposures, perceived heat stress, measured heat strain symptoms, and self-reported health impacts were collected with informed consent. Blood test for kidney function was assessed in 30% of consenting subjects. HSI and renal function were measured (twice) in 73 workers to identify seasonal variation.

Assessment of heat exposure

Wet bulb globe temperature (WBGT) was measured in workplaces at various times each study day using a calibrated portable heat stress WBGT monitor (QuesTemp°34; QUEST Technologies, USA) with a 0.5°C accuracy level between 0°C and 120°C of dry bulb temperature and 5% relative humidity. The WBGT accounts for the effects of four primary thermal components influencing heat stress: air temperature, humidity, radiation, and air velocity, as measured by the dry bulb, wet bulb, globe temperatures, and anemometer. The WBGT index is the most widely used heat index[4,5] to define heat exposure threshold limits.[6] Using the allowable heat exposure threshold limit values (TLV),[7,8] we calculated the risk of heat stress and the corresponding WBGT under which one hour of continuous work can be performed safely.

The WBGT monitor was mounted on a tripod and kept away from anything impeding radiant heat or ventilation. WBGT meters were placed at 3.5 feet (1.1 m) and 2 feet (0.6 m) height for standing and seated individuals, respectively. Heat exposure was measured continuously using EL-USB-2-LCD+ portable data loggers. Industrial hygienists and project staff established sampling times and locations depending on work technique, workload, clothing, and acclimatization.

We categorized participants by WBGT and 27.5°C and 28°C ACGIH TLVs for heavy and moderate workloads, respectively, to measure heat stress risk on inquiry day.

Participants' perception of the heat-related health impacts

The standardized and validated high occupational temperature health and productivity suppression (HOTHAPS) questionnaire [Supplementary File B] was used to collect data on participants' perceptions. The questionnaire assessed demographics, work, heat exposure, health and productivity impacts, clothing, coping mechanisms, social life impacts, welfare facility access, menstrual history, kidney-related, and other chronic disease questions. The investigators made observations of the workplace conditions, occupational exposures, and any cooling interventions. A trained interviewer clarified any ambiguous responses. Self-reported heat stress symptoms were detailed, and the interviewer explained each condition in the local language. Questionnaire administration took about 20 minutes. The questions were polar. Specific answers revealed heat stress's health, productivity, and social consequences.

Quantitative heat strain assessments

Core body temperature (CBT), sweat rate (SwR), heart rate (HR), and urinary parameters (pH, urine specific gravity, hematuria, proteinuria) were measured individually. A stable digital weighing scale (Dr.Gene, model no. MS-7703) measured weight, and a stadiometer (Model SM-01) measured height. Workers were told to wear street clothes and remove PPE.

CBT was measured with an infrared thermometer (IR) (BRAUN ThermoScan® IRT 6020) before heat exposure (pre-exposure CBT) and after continuous 3–4 hours of heat exposure (post-exposure CBT). IR is non-invasive and measures tympanic temperature without causing discomfort. Therefore, it is convenient and accepted for field measurement.[9] CBT differences pre-exposure and post-exposure >1°C were considered abnormal.[10] The Canadian sports formula (SWR (L/h) = [(Pre-Work Body Weight - Post-Work Body Weight) + Fluid Intake During Work (L) - Urine Output (L)] / Work Duration (hours) was utilized to calculate SwR.[11] SwR >1 L/hr was regarded as excessive.[5] Each participant received a measured water bottle, and extra water intake was recorded. Urine-specific gravity was measured pre- (just before the work starts), mid- (immediately preceding the lunch break), and post-shift (end of the shift) with an ATC clinical portable refractometer, and urine-specific gravity > 1.020 was deemed elevated.[11-13] A urine dipstick (Dirui H10) was used to measure proteinuria, hematuria, pH, and urine-specific gravity. The normal urine-specific gravity was set between 1.002 and 1.020,[13,14] and a urine color chart was used as a proxy measure to assess dehydration level.[15] A Polar M430 Bluetooth watch was used to monitor HR while seated after the task completion, and a rate >100 beats per minute was considered abnormal.[7,16]

Kidney function tests

Venous blood samples were collected before and after work shifts, and serum creatinine concentrations were determined using the classic Jaffe method calibrated against isotope dilution mass spectrometry (IDMS)-traceable standard.[17] The eGFR was calculated using the CKD-EPI equation.[18]

Statistical analysis

The data were entered into Microsoft Excel 2013 and analyzed using SPSS software version 19.0 (IBM Corporation, New York, USA). Frequencies and proportions were used to describe categorical variables, while 95% confidence intervals (CI) and means with standard deviations were used to describe continuous variables.

WBGT is the exposure variable; the self-reported and measured physiological heat strain indicators and the serum creatinine are outcome variables. Bivariate analysis was done using the χ^2 test and t-test. Logistic regression analyses were performed to estimate crude odds ratios (CORs) of WBGT-associated factors and heat stress-related variables, such as age, gender, education, smoking, alcohol consumption, and years of exposure. Multivariate regression analysis was done stepwise. First, significant confounders were determined using the χ^2 test. Then, multivariate analysis choosing all covariates with a *p*-value <0.05 to adjust as confounding variables to determine any significant association with these variables was done. We present both un-adjusted and adjusted odds ratios (AOR) in the multivariate model. A paired t-test compared the changes in pre- and post-shift physiological parameters.

Results

A total of 596 participants, 358 and 238, during the hotter and cooler seasons, respectively, were evaluated. Of them, 60.1% were males and 39.9% were females. The age range was 18-75, with a median age of 42 years [Table 1]. The occupation distribution among males and females has been mentioned in Supplementary Figure 1. Illiteracy was higher among females (60.9%) than males. Males had significantly higher alcohol use (68.4%) and smoking (43.6%) [Table 1].

A total of 208 (58%) and 150 (42%) male participants had heavy and moderate workloads, respectively. About 81% and 19% of females had heavy and moderate workloads, respectively. Based on all observations (n=669), the TLV data categorized 455 (68%) as heat-exposed and the remaining (n=214, 32%) as unexposed.

Heat stress profiles

Figure 1 depicts WBGT (°C) exposures, ranging from 28.0°C in Kondavoru (poultry farm) to 41.6°C in Iddivanipalem (agriculture with direct sun exposures), with an average of 31.7°C ± 2.2°C during the hotter season. Cooler season WBGT varied from 19.6°C in Kusumpuram (agriculture) to 31.7°C in Haripuram (coir production exposed to ambient heat), with a 25.5°C ± 2.5°C average. Cashew boiling (3.0%; n=18/596), agriculture (14.0%; n=84/596), and

Table 1: Demographic characteristics of study participants

Particulars	Male (n=358)	Female (n=238)	Total (n=596)
Number of participants	358 (60.1)	238 (39.9)	596 (0)
Age (years)	41 (32,74)	38 (33,70)	42 (35,70)
Years of exposure to heat	14 (6,50)	10 (6,40)	15 (8,50)
Level of education			
Illiterate	145 (40.5)	145 (60.9)	290 (48.7)
Literate school	187 (52.2)	87 (36.6)	274 (46.0)
Attended college	26 (7.3)	6 (2.5)	32 (5.4)
Alcohol use	245 (68.4)	2 (0.8)	245 (41.1)
Smoking	156 (43.6)	0	156 (26.2)
Body mass index (kg/m^2)			
<18.5	66 (18.4)	35 (14.7)	101 (16.9)
18.6-22.9	142 (39.7)	94 (39.5)	236 (39.6)
23.0-24.9	55 (15.4)	43 (18.1)	98 (16.4)
≥25.0	95 (26.5)	66 (27.7)	161 (27)
Workload			
Heavy	208 (58.1)	193 (81.1)	401 (67.3)
Moderate	150 (41.9)	45 (18.9)	195 (32.7)
Heat exposure			
Above TLV (Exposed)	234 (65.4)	148 (62.2)	382 (64.1)
Below TLV (Unexposed)	124 (34.6)	90 (37.8)	214 (35.9)

Note: Workload was categorized as per ACGIH 2021; Exposed: Heavy workload above 27.5 °C WBGT, moderate work load above 28.0 °C WBGT; Unexposed: Heavy work, ACGIH: American conference of governmental industrial hygienists, WBGT: Wet bulb Globe temperature, TLV: Threshold limit value, IQR: Interquartile range construction (12.2%; n=73/596) had the most workers crossing the safe limit, followed by the coir industry 9.6%; n=57/596), fishing (9%; n=53/596), animal husbandry (5.9%; n=35/596), and stone quarry (5.7%; n=34/596). In the hotter season, nearly all workers were subjected to excessive heat and exceeded the safe TLV limit, whereas, in the cooler season, 16.7% of workers (n=43) were exposed to heat levels that exceeded the TLVs. 64.1% of participants experienced heat exposure above TLV, with 65.4% of males (n=234) and 62.2% of females (n=148) exposed. On the other hand, 34.6% of males (n=124) and 37.8% of females (n=90) remained unexposed, accounting for 35.9% of the participants. Based on the number of participants recruited, males had slightly higher exposure rates [Table 1 and Supplementary File C].

Behavioral risk factors and self-reported heat strain symptoms

The average water intake per shift was 1.2 L for male workers and 1.0 L for female workers. Most heat-exposed participants (98.5%, n = 448) reported heat stress symptoms, such as increased sweating, excessive thirst, muscle cramps, prickly heat, headaches, nausea, vomiting, and dizziness. Approximately one-third of the participants with exposures above TLV reported excessive sweating (83%, n = 376), headache (55%, n = 251), extreme thirst (60%, n = 271), changes in urine volume/color/burning sensation (87%, n = 395), muscle cramps (72%, n = 329), and symptoms of dehydration (45%, n = 206) [Table 2].

Heat strain indicators

A total of 55 (12%) participants in the heat-exposed group experienced a cross-shift increase in CBT >1 °C, compared to 1% in the unexposed group [Table 2]. The CBT >1°C rise risk was nearly 14.5-fold greater among exposed participants (95% CI: 3.5-60.3) [Table 2]. Compared to 3.7% of unexposed participants, 10% (n = 46) of heat-exposed participants had sweat rates above the normal threshold[5] [Table 2].

A total of 198 (43%) heat-exposed and 56 (26%) unexposed participants demonstrated high urine-specific gravity, another heat strain indicator. Higher post-shift urine-specific gravity was observed among those working above TLV, correlating with sweat loss and self-reported dehydration. The measured physiological responses of the exposed and unexposed workers have been shown in Table 3. The two groups' pre- and post-shift heart rates, CBT, urine specific gravity, pH, and serum creatinine differed significantly (*p*-value<0.001). In both groups, it was found that other markers, including hematuria and leukocyturia, were higher post-shift than pre-shift.

Heat-exposed workers reported increased heat stress, urogenital symptoms, such as changes in urine color, volume, and burning sensation, and dehydration symptoms regardless of the season [Table 2]. The exposed group reported 6.2 times as many heat stress symptoms. Even after accounting for education, alcohol consumption, smoking, and years of exposure, those in the exposed category had 2.6- and 7.1-fold increased urogenital and dehydration symptom risk, respectively. Similar patterns were observed for HSI and HRI [Table 2]. Heat strain indicators such as CBT, SwR, and/or increased urine specific gravity[12] were 1.9 times higher (95% CI: 1.3,2.9) in participants with high heat exposures and physically demanding occupations.

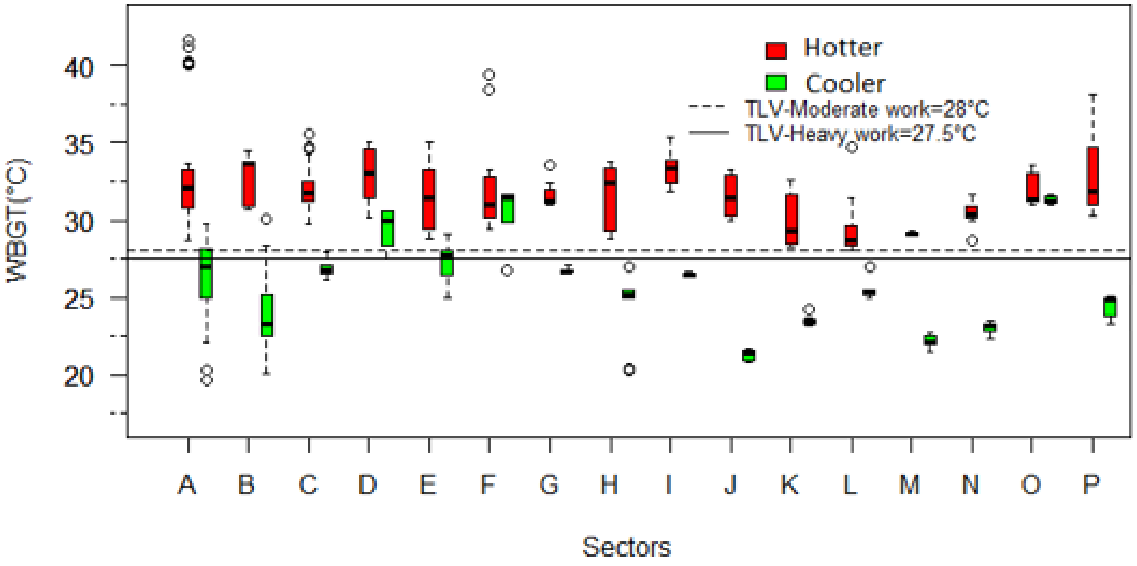

Figure 1: Attributed Wet Bulb Globe Temperature (WBGT °C) profiles across various Occupational sectors (2020-2022) in Uddanam, Andhra Pradesh. Note: A: Agriculture, B: Brick kiln, C: Construction, D: Animal Husbandary, E: Coir industry, F: Cashew boiling, G: Stone Quarry, H:Welding, I: Mahatma Gandhi Rural work, J: Kirana shop, K: Cashew cutting, L: Poultry farm, M: Primary Health Centre, N: Carpenting, O: Anganwadi, P: Fishing, TLV: Threshold limit value.

Table 2: Association between occupational heat stress (exposed vs unexposed), self-reported and measured physiological heat strain indicators for the study population (N=669)

Study variables	Exposed ^{a}n=455	Unexposed ^{b}n=214	*p*-value	COR$^{\neq}$ (95% CI)	AOR$^{\neq ¥}$ (95% CI)
Self-reported heat strain symptoms					
Excessive sweating	376 (82.6)	164 (76.6)	0.06	1.4 (0.9,2.1)$^{€}$	
Excessive thirst	271 (59.6)	183 (85.5)	0.0001	0.2 (0.1,0.3)$^{€}$	
Dysuria	126 (27.7)	26 (12.1)	0.0001	2.7 (1.7,4.3)	**2.5 (1.5,4.1)**
Nausea/Vomiting/prickly heat	11 (2.4)	8 (3.7)	0.638	0.6 (0.2,1.6)$^{€}$	
Tiredness/weakness	84 (18.5)	53 (24.8)	0.059	0.6 (0.4,1.0)$^{€}$	
Muscle cramps	329 (72.3)	82 (38.3)	0.0001	4.2 (2.9,5.9)	**3.5 (2.4,5.0)**
Swollen legs/hands	302 (66.4)	24 (11.2)	0.0001	15.6 (9.7,24.9)	**14.3 (8.8,23.2)**
Dizziness	156 (34.3)	12 (5.6)	0.0001	8.7 (4.7,16.2)	**7.7 (4.1,14.6)**
Headache	251 (55.2)	133 (62.1)	0.088	0.7 (0.5,1.0)$^{€}$	
Self-reported heat strain symptoms (Any one mentioned above)	448 (98.5)	195 (91.1)	0.0001	6.2 (2.5,15.0)	**5.7 (2.2,14.9)**
Symptoms of dehydration (Dry mouth, excessive thirst)	206 (45.3)	20 (9.3)	0.0001	8 (4.8,13.1)	**7.1 (4.3,12.0)**
Symptoms of Uro-genital issues (Changes in urine color, volume, and burning sensation)	395 (86.8)	156 (72.9)	0.0001	2.4 (1.6,3.6)	**2.6 (1.7,4.1)**
Measured heat strain indicators (HSI)					
CBT (pre-post shift difference > 1°C)	55 (12.1)	2 (0.9)	0.0001	14.5 (3.5,60.3)	**12.1 (2.9,51.1)**
Sweat rate ≥1L/hr	46 (10.1)	8 (3.7)	0.005	2.8 (1.3,6.2)	**2.7 (1.2,6.1)**
Urine specific gravity ≥1.020	198 (43.52)	56 (26.2)	0.0001	2.1 (1.5,3.1)	**1.9 (1.3,2.9)**
Heat strain indicators (any of the above)	228 (50.1)	59 (27.6)	0.0001	2.6 (1.8,3.7)	**2.4 (1.6,3.5)**
eGFR<90 mL/min/1.73m^{2} (n=266)	146 (76)	42 (56.8)	0.002	2.4 (1.3,4.2)	**2.1§ (1.1,3.7)**
eGFR<60 mL/min/1.73m^{2} (n=266)	32 (16.7)	15 (20.3)	0.49	0.7 (0.4,1.5)$^{€}$	

Note: ≠More than 1 denotes the presence of risk; ¥ Adjusted for confounders and effect modifiers such as age, education, alcohol, smoking, years of exposure. § Adjusted for age, smoking; ^{a}Exposed: Heavy workload above 27.5°C WBGT, moderate workload above 28.0°C WBGT; Unexposed: ^{b}(Reference category) Heavy workload below 27.5°C WBGT, moderate workload below 28.0°C WBGT (ACGIH 2021); $^{€}$ As chi square value is non-significant, No AOR. Bold indicates significant values. eGFR: estimated glomerular filtration rate, CBT: Core body temperature, COR: Crude odds ratio, AOR: Adjusted odds ratio, CI: Confidence interval, ACGIH: American conference of governmental industrial hygienists, WBGT: Wet bulb Globe temperature

Table 3: Physiological heat strain measurements of the exposed and unexposed workers (N=669)

Parameters	Exposed			Unexposed		
	Pre-Shift	Post Shift	*p*-value$^{¥}$	Pre-Shift	Post Shift	*p*-value$^{¥}$
Physiological indicators of heat strain						
Heart rate (Beats/minute)	83 (51,115)	90 (63,146)	**<0.001**	80 (60,146)	91 (60,161)	**<0.001**
CBT (°C)	37 (36.3,38.2)	37.5 (36.9,38.3)	**<0.001**	37.1 (36.0,37.6)	37.4 (36.9,38.1)	**<0.001**
Sweat rate (L/hr)	0	0.6 (0,1.3)	NA	-	0.5 (0,1.1)	NA
Body weight	56.2 (31.0,92.0)	55.1 (30.0,91.6)	**<0.001**	58.0 (35.0,90.0)	58.0 (35.0,89.0)	**<0.001**
Urine specific gravity	1.02 (1.002,1.025)	1.015 (1.002,1.028)	**<0.001**	1.020 (1.005,1.020)	1.015 (1.010,1.025)	**<0.001**
pH	6 (5.0,6.5)	6 (5.0,6.5)	**<0.001**	6 (5.0,6.5)	6 (5.0,6.5)	**<0.001**
Serum creatinine (mg/dL)	1 (0.6,4.2)	1.1 (0.6,5.1)	**0.001**	1 (0.6,3.2)	1 (0.6,3.5)	**0.016**
eGFR (mL/min/1.73m^{2})	77.6 (16.5,129.5)	74.2 (13.07,128.4)	**0.002**	83.9 (18.7,136.8)	86 (16.8,125.9)	0.266
Proteinuria (mg/dL)						
Negative	403	324	**<0.001**	180	178	0.936
Trace	2	8		23	27	
1+	31	63		8	6	
2+	13	47		1	2	
3+	6	13		2	1	
4+	0	0		0	0	
Hematuria (RBC/µL)						
Negative	453	449	0.5830	213	208	0.634
Trace	0	0		0	5	
1+	0	5		0	0	
2+	0	0		0	0	
3+	2	1		1	1	

¥paired t test. NA: Not applicable; Bold indicates significant values.

Table 4: Association between season, self-reported and measured physiological heat strain indicators for the study population (N=669)

Study variables	Hotter season n=412	Cooler season n=257	*p*-value	COR[≠] (95% CI)	AOR[¥] (95% CI)
Self-reported heat strain symptoms					
Excessive sweating	349 (84.7)	191 (74.3)	0.001	1.9 (1.3,2.8)	1.7 (1.1,2.7)
Excessive thirst	235 (57)	219 (85.2)	0.0001	0.2 (0.1,0.3)[€]	-
Dysuria	123 (29.9)	29 (11.3)	0.0001	3.3 (2.1,5.2)	3.2 (2.0,5.1)
Nausea/Vomiting	7 (1.7)	12 (4.7)	0.024	0.3 (0.1,0.9)[€]	-
Tiredness/weakness	67 (16.3)	70 (27.2)	0.001	0.5 (0.3,0.7)[€]	-
Muscle cramps	300 (72.8)	111 (43.2)	0.0001	3.5 (2.5,4.9)	2.8 (2.0,4.0)
Swollen legs/hands	298 (72.3)	28 (10.9)	0.0001	21.3 (13.6,33.4)	23 (14.1,37.3)
Dizziness	151 (36.7)	17 (6.6)	0.0001	8.1 (4.8,13.8)	7.6 (4.4,13.3)
Headache	222 (53.9)	164 (63)	0.02	0.7 (0.5,0.9)[€]	-
Self-reported heat strain symptoms (Any one mentioned above)	406 (98.5)	237 (92.2)	0.0001	5.7 (2.3,14.4)	5.2 (2.0,14.3)
Symptoms of dehydration (Dry mouth, excessive thirst)	200 (48.5)	26 (10.1)	0.0001	8.3 (5.3,13.1)	7.9 (5.0,12.7)
Symptoms of Uro-genital issues (Changes in urine color, volume, and burning sensation)	359 (87.1)	192 (74.7)	0.0001	2.3 (1.5,3.4)	2.5 (1.6,4.0)
Measured heat strain indicators					
CBT (pre-post shift difference $>$ 1°C)	55 (13.3)	2 (0.8)	0.0001	19.6 (4.7,81.2)	17.5 (4.1,74.1)
Sweat rate ≥1L/hr	44 (10.7)	10 (3.9)	0.002	2.9 (1.4,6.0)	2.8 (1.3,6.0)
Urine specific gravity ≥1.020	184 (44.7)	70 (27.2)	0.0001	2.1 (1.5,3.0)	2 (1.4,2.9)
Heat strain indicators (any of above)	213 (51.7)	74 (28.8)	0.0001	2.6 (1.9,3.7)	2.5 (1.7,3.5)
eGFR<90 mL/min/1.73m^2 (n=266)	130 (76.5)	58 (60.4)	0.006	2.1 (1.2,3.6)	2.0[§] (1.1,3.5)
eGFR<60 mL/min/1.73m^2 (n=266)	29 (17.1)	18 (18.8)	0.728	0.9 (0.4,1.7)[€]	-

[≠] More than 1 denotes the presence of risk; [¥] Adjusted for confounders and effect modifiers such as age, education, alcohol, smoking, years of exposure; [§] Adjusted for smoking; [€] Chi square non-significant.

Next, we compared the heat-related symptoms and heat exposure parameters during the cooler and hotter seasons in Table 4. After controlling known variables, there was a 5.2-fold increase in the probability of workers reporting HRI symptoms during hotter seasons (95% CI:2.0,14.3) even after adjusting for confounders. Self-reported dehydration, urogenital issues, and measured HSI (CBT, urine specific gravity, and SwR) increased during hotter months (95% CI = 1.7,3.5). During hotter seasons, decreased kidney function risk (eGFR <90 mL/min/1.73m^2) was 2.0-fold higher (95% CI: 1.1,3.5) among the heat-exposed workers [Table 4].

Cross-shift measures over a workday were performed in both seasons for 73 participants [Supplementary File D]. The heat strain symptoms were less pronounced in cooler seasons. Cross-shift variations in the measured HSI, such as CBT (°C) (12.5%), SwR (9.3%) and urine-specific gravity (33.3%), were higher in hotter seasons. Cross-shift variations in eGFR were also less pronounced in cooler seasons, although this difference was not statistically significant.

Discussion

This is the first study assessing heat exposure in Uddanam, Srikakulam district, Andhra Pradesh, a heat wave and CKDu hotspot.[19] According to literature from other countries with high CKDu prevalence, exposure to excessive ambient heat is a main explanation. CKD is common in Uddanam farmers, agricultural laborers, and outdoor occupations.[20] No systematic heat exposure assessment has been done.

WBGTs exceeded safe working TLVs for most outdoor workers. Season significantly affected HRIs and HSIs. The post-shift urine-specific gravity showed moderate to severe dehydration, as observed in hot job environments. Agricultural workers were more exposed to direct sunlight during the hottest months, while coir workers were at high heat-related symptom risk year-round due to intense workloads and poorly ventilated workspaces. Heavy manual workers exceeded safe TLV limit more often than moderate workers, regardless of season.[21] Male participants had a higher water intake compared to females during the hotter season. This difference may be due to heavier physical workload. High heat, poor fluid intake, and heavy perspiration cause common HRI and dehydration symptoms.[11] Even the unexposed group and records from the cooler season showed excessive thirst, urine-specific gravity, and eGFR, which is not surprising considering that workload, less water intake, and inadequate workplace welfare facilities also affect the physiological strain. Heat exposure and exertion cause whole-body water changes,[22] and body mass loss, which dehydrates and elevates urine-specific gravity,[23] which can compromise renal function with repeated exposures.[2] Swelling in the extremities, particularly during heat exposure, can be a fluid retention indicator, signaling dehydration, electrolyte imbalance, or early signs of heat-related illness. Rhabdomyolysis, hypotension, and renal damage can ensue from chronic dehydration.[24] Inaccessible potable water and inadequate sanitation in the workplace could increase heat-related health risks, including excessive thirst, by preventing female workers from drinking enough water to replace sweat lost due to heat and exertion and reducing urination.[25]

Heat exposure is linked to reduced eGFR in other groups.[26] Heat exposure doubled the chance of kidney damage, and nearly half experienced HSI symptoms beyond the permissible range.[27] This study had many participants with eGFRs < 90 mL/min and < 60 mL/min. This could be due to constant heat exposure, frequent dehydration, or hyperosmolar stress, all of which could affect kidney function over time. In addition, socio-economic factors, poor hydration practices, and limited healthcare access could exacerbate underlying vulnerabilities.

Like this study, heat stress, heavy labor, and warmer seasons increased the renal function decline probability.[28-30] SwR, higher body core temperatures, and longer work hours can aggravate heat-induced tubular kidney injury.[31] Increased proteinuria could be attributed to the physiological stress induced by heat exposure, which may lead to transient renal dysfunction that alters renal hemodynamics, including reduced renal blood flow and GFR, potentially leading to protein leakage in the urine. Hydration and work-rest balance can reduce renal disease risk.[32] In-depth studies on occupational heat stress and kidney health risk reduction can help design safe work practices like water-rest-shade and improve workers' welfare facilities.

Our study is notable for being the first to examine occupational heat exposures and renal health in high-CKDu endemic India. The systematic extensive WBGT monitoring, adjusted with TLV, season and physiological monitoring, and HOTHAPS questionnaire evaluation of heat-related symptoms, allowed a comparison between the jobs' physical demands and heat exposure levels.

This study has many limitations. Preliminary screening was based on self-reported symptoms, which may not be accurate. Although the population was broadly representative, the number of participants varied between different sectors. We measured tympanic membrane temperature, which is not the most reliable method to monitor CBT. We measured the tympanic temperature three to five times to overcome this and averaged the results. This study primarily aimed to assess the extent of heat exposure and its physiological burden on workers. In other studies, CKDu has been suggested as a possible result of repeated heat stress. However, we only showed a high perceived symptom burden and physiological stress, which may make people more likely to develop kidney dysfunction over time, not proving any definitive causality claims. Another limitation is that this study emphasized “eGFR <90” to primarily be an indicator of physiological kidney response to heat rather than a standalone diagnostic criterion for kidney disease, which is exploratory at this stage. This study did not exclude individuals with pre-existing renal dysfunction, as the focus was on capturing occupational heat exposure's broader impact across the working population. Future studies could consider stratifying or excluding such individuals based on their renal history to ensure more targeted analyses. Finally, this study is largely cross-sectional; repeat measurements (longitudinal study design) are needed to assess heat stress's impact on overall and kidney health. These limitations notwithstanding, the study highlights important new findings and has preventive policy implications for the working population that is exposed to high-heat environments daily.

In conclusion, heat exposure, self-reported heat strain symptoms, and HSI measurements in the study population have close association. Heat stress and strain were stronger among exposed participants. Dehydration was common, indicating poor heat stress management and hydration practices. Heat stress and strenuous work in hotter seasons can lead to kidney function deterioration. This requires a holistic response to occupational heat stress involving home, local, and technical approaches. Larger epidemiological studies using kidney biomarkers are planned to understand CKDu etiology better. Comprehensive protective labor laws require more research and evidence to protect the health of those exposed to excessive heat.

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