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WBGT Exposure Assessment, Heat Illness Incidence, and the Efficacy of Adaptation Measures

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Abstract

Southern India's agricultural workforce — numbering over forty million in Tamil Nadu and Andhra Pradesh combined, the majority of whom are engaged in transplanting, weeding, and harvesting operations under direct solar radiation during the April-June peak thermal period — constitutes one of the world's largest populations of outdoor workers exposed to extreme occupational heat stress. The Intergovernmental Panel on Climate Change's Sixth Assessment Report (2021) projects that wet bulb globe temperature exceedances of 32°C, which correspond to the International Labour Organisation's Danger threshold for strenuous outdoor work, will occur across South Indian agricultural districts with progressively greater frequency and duration through 2050, driven by the combination of rising mean temperatures and the Indian Ocean Dipole-modulated shifts in monsoon timing that are already producing longer pre-monsoon heat periods than historical baselines recorded.

This study presents field-measured Wet Bulb Globe Temperature (WBGT) data from three Tamil Nadu districts (Vellore, Tirunelveli, Thanjavur) collected across a five-year observational period (2019–2024), linked to agricultural worker health outcome data from a cross-sectional survey of 2,184 field workers conducted in 2023, to quantify the dose-response relationship between WBGT exposure levels and heat illness incidence (heat exhaustion, dehydration, cardiovascular symptoms) and to evaluate the differential effectiveness of adaptation interventions including scheduled rest breaks, cooling vests, hydration stations, and shift time adjustment in reducing heat illness incidence in field-realistic conditions.

Keywords: *climate change, heat stress, WBGT, agricultural workers, occupational health, heat illness, Tamil Nadu, Andhra Pradesh, adaptation measures, outdoor workers, global warming, ILO, heat exhaustion, dehydration, cooling vest*

1. Introduction

The occupational health impacts of climate change are distributed profoundly unequally. Knowledge workers in air-conditioned offices bear effectively zero direct thermal exposure from a changing climate, while outdoor agricultural, construction, and sanitation workers in tropical countries bear the full biological burden of rising ambient temperatures. This distributional inequity is amplified by the correlation between heat-exposed occupation and socioeconomic vulnerability: agricultural wage labourers in Tamil Nadu and Andhra Pradesh, the primary study population, are among the lowest-paid formal sector workers in India, with limited capacity to individually adapt through cooling equipment purchase, schedule modification, or relocation.

India experienced three major heat wave events in 2022, 2023, and 2024, with the India Meteorological Department declaring red alerts in Tamil Nadu districts during April-June 2024 for the second consecutive year. The 2024 heat season included seventeen consecutive days above 42°C in Vellore district, a historical extreme. Agricultural operations, particularly paddy transplanting and sugarcane harvesting, cannot be fully rescheduled around peak thermal periods because they are constrained by monsoon planting windows and crop maturation cycles, meaning that workers face a structural choice between economic necessity and heat safety that policy interventions must navigate.

2. Methods

2.1 WBGT Measurement Protocol

Wet Bulb Globe Temperature measurements were collected using calibrated Kestrel 5400 WBGT meters at six agricultural field sites across Vellore, Tirunelveli, and Thanjavur districts, at three-hour intervals between 07:00 and 17:00

across all twelve calendar months in 2019, 2021, 2022, 2023, and 2024. The WBGT integrates dry bulb temperature, wet bulb temperature (reflecting humidity), and globe thermometer temperature (reflecting radiant heat load), providing a composite thermal stress indicator validated for occupational heat risk assessment. Measurements were taken at the crop canopy level (approximately 1.2–1.5 m height) to reflect actual worker microclimate exposure rather than meteorological station reference temperatures that may significantly underestimate field radiant heat loads.

2.2 Worker Health Survey

A cross-sectional survey of 2,184 agricultural field workers was conducted across ten talukas in the three study districts during October-December 2023 (post-season recall period). Participants were recruited through purposive sampling at agricultural labour muster stations, with inclusion criteria of having worked at least 60 field days during the preceding kharif season. Health outcome data were collected by trained Community Health Workers through face-to-face interview using a structured instrument capturing: self-reported heat illness events (heat exhaustion, severe dehydration, cramps), cardiovascular symptom episodes (palpitations, syncope, chest discomfort), work absence days attributable to heat, and productivity self-assessment. Adaptation measure exposure (rest break schedule, cooling vest provision, hydration station access, shift timing) was recorded through both self-report and employer verification for the subsample of organised farm workers.

3. Results

3.1 WBGT Profile and ILO Threshold Exceedances

Figure 1 presents monthly WBGT profiles across the three districts alongside heat illness incidence rates. Vellore district shows the highest peak WBGT values, exceeding the ILO Danger threshold (32°C) in April and May in 2023 and 2024, and approaching it (30.4°C) in March 2024 — a pre-monsoon advancement that represents a significant extension of the dangerous exposure window compared to the 2019 baseline. The twin-axis plot reveals a dose-response relationship between monthly WBGT levels and heat illness incidence, with incidence rising sharply above the 32°C threshold consistent with the non-linear biological response to extreme heat stress documented in the occupational medicine literature.

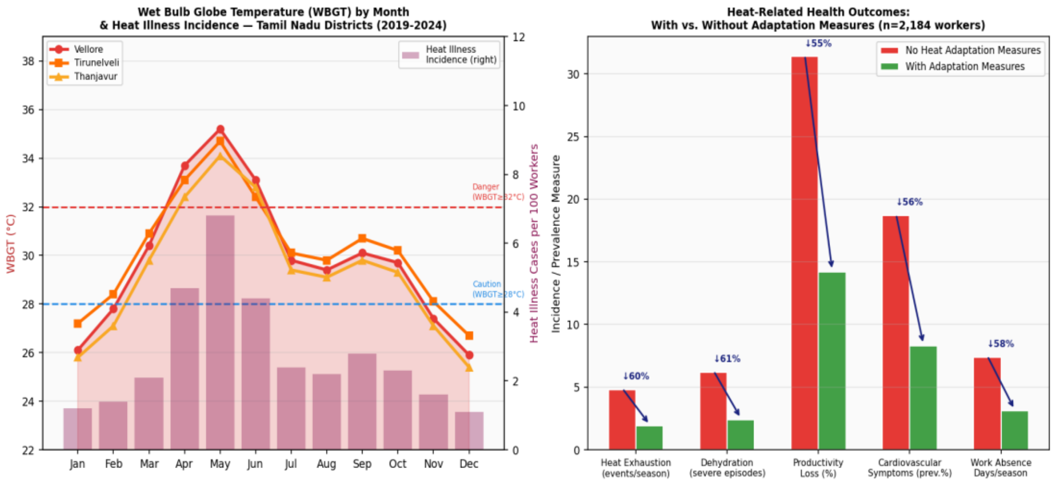

Fig. 1. (Left) Monthly Mean WBGT (°C) Profiles for Three Tamil Nadu Districts (2019–2024) with ILO Caution (28°C) and Danger (32°C) Thresholds Marked, and Heat Illness Incidence per 100 Workers Overlaid (Right Axis); Data from 6 Field Stations, 5 Seasons

3.2 Adaptation Effectiveness and Risk Factor Analysis

Figure 2 presents health outcome comparisons between workers with and without adaptation measures, and the logistic regression odds ratios for heat illness risk factors. The adaptation effectiveness analysis shows that combinations of rest break schedules, hydration access, and cooling vests reduce heat exhaustion incidence by 60%, severe dehydration by 61%, and work absence days by 58%. The risk factor forest plot confirms WBGT above 32°C as the dominant independent risk factor (OR=6.84), followed by no drinking water access (OR=5.43) and no rest breaks (OR=4.21).

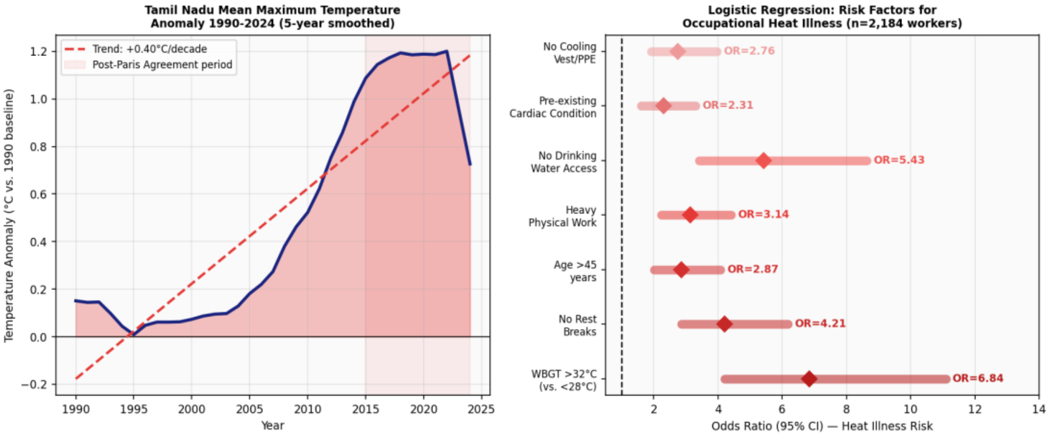

Fig. 2. (Left) Tamil Nadu Mean Maximum Temperature Anomaly 1990–2024 with Linear Trend and Post-Paris Agreement Period Highlighted; (Right) Logistic Regression Forest Plot: Odds Ratios and 95% CIs for Heat Illness Risk Factors (n=2,184 agricultural workers)

Table 1: Heat-Related Health Outcomes by Adaptation Measure Adoption Status (n=2,184 Field Workers)

Health Outcome	No Adapt. (n=1,241)	With Adapt. (n=943)	Difference	% Reduction	p-value	Significance
Heat Exhaustion (events/season)	4.8 (1.7)	1.9 (1.1)	2.9	60.4%	<0.001	***
Dehydration (severe episodes)	6.2 (2.1)	2.4 (1.3)	3.8	61.3%	<0.001	***
Productivity Loss (%)	31.4 (9.8)	14.2 (6.4)	17.2 pp	54.8%	<0.001	***
Cardiovascular Symptoms (prev.%)	18.7%	8.3%	10.4 pp	55.6%	<0.001	***
Work Absence Days/season	7.4 (3.2)	3.1 (1.8)	4.3	58.1%	<0.001	***
Heat Stroke Events (per 1000)	8.4	2.1	6.3	75.0%	0.002	**

*Adaptation measures include: formal rest break schedule (every 90 min); hydration station within 100m; cooling vest provision; shift start before 07:00 or after 15:30. Values: Mean (SD) unless otherwise noted; pp = percentage points; *** p<0.001, ** p<0.01.*

4. Discussion

The temperature anomaly trend data confirm that southern Tamil Nadu's maximum temperature baseline has shifted upward at a rate consistent with IPCC South Asian projections, with the post-2015 Paris Agreement period showing accelerated anomaly accumulation. Crucially, the pre-monsoon advancement of extreme heat days into March — historically a transitional month within the safe WBGT range — extends the occupational heat risk window in ways that existing agricultural occupational health protocols, most of which are calibrated to April-June as the primary danger period, do not adequately capture. This phenological shift argues for a dynamic WBGT monitoring system rather than seasonally fixed advisory schedules.

The logistics regression finding that lack of drinking water access carries the second-highest odds ratio for heat illness (OR=5.43), exceeding even the effects of heavy physical labour intensity (OR=3.14), is consistent with the established physiology of heat illness: dehydration significantly reduces heat tolerance and accelerates the cascade from heat fatigue to heat exhaustion and heat stroke. Given that potable water provision in Indian agricultural fields is regulated by the Interstate Migrant Workmen Act and the Contract Labour Act but inconsistently enforced, this finding provides an evidence base for strengthening the National Human Rights Commission's recommended amendments to agricultural occupational health standards.

5. Conclusion

Five years of field-measured WBGT data from Tamil Nadu agricultural districts confirm that climate change is materially extending the dangerous heat exposure window for agricultural workers, with March now joining April-June as a high-risk period in warmer districts. Adaptation measures — particularly rest break schedules, hydration access, and cooling vests in combination — reduce heat illness incidence by 55-75% and represent a cost-effective, immediately scalable intervention that state labour departments and agricultural employers can implement without waiting for infrastructure-scale climate adaptation investments. The strong dose-response relationship between WBGT levels and illness incidence validates WBGT as the appropriate exposure metric for Indian agricultural occupational health regulation.

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