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Poonguzhali R.P.
Brinda Viswanathan
K.S. Kavi Kumar

MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai 600 025
India

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Poonguzhali R. P.
Pre-doctoral fellow, Indian Institute of Management, Bangalore

Brinda Viswanathan
Professor, Madras School of Economics, Chennai;
brinda@mse.ac.in

and

K.S. Kavi Kumar
Professor, Madras School of Economics, Chennai

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MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai600 025
India

Phone: 2230 0304/2230 0307/2235 2157
Fax: 2235 4847/2235 2155
Email : info@mse.ac.in
Website: www.mse.ac.in

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Abstract

Changing climatic conditions are likely to increase the heat stress and the corresponding risk of vulnerable population in society. This study investigates the impact of heat stress on rural women in India aged 15-35, using the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 5 (AR5) risk assessment framework. The study uses Universal Thermal Climate Index (UTCI) data sourced from the Copernicus Climate Change Service from 1994 to 2024 to assess heat stress, and demographic and social indicators from National Family Health Survey (NFHS) 2015–2016 for constructing the risk index. By integrating environmental and demographic indicators for rural women to analyse the impact of heat stress, the study reveals regional disparities in heat stress risk. The results suggest that while Jharkhand, Madhya Pradesh and Bihar rank highest in terms of heat stress risk, Sikkim and Himachal Pradesh exhibit low risk. Southern states like Kerala and Tamil Nadu despite facing high heat stress, exhibit relatively lower heat stress risk due to better adaptive capacity. These results highlight the need for region-specific targeted policy interventions to mitigate the effects of heat stress among rural Indian women.

Keywords: *Universal Thermal Climate Index, Heat Stress, Risk Assessment, India, Women*

JEL Codes: *Q54, I15, J16, O13, R11*

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Poonguzhali R P
Brinda Viswanathan
K.S. Kavi Kumar

INTRODUCTION

Background of Study

Climate change is one of the most important worldwide issues of the twenty-first century and has a significant effect on ecosystems, economies, human health, and livelihoods. As per the Global Climate Risk Index, India is extremely vulnerable to heatwaves, droughts, and other climate hazards due to its geographic and demographic features (Venugopal et al., 2020). As a result of urbanization and climatic intensification, the number of Indian states experiencing heatwaves increased from nine to twenty-three between 2015 and 2020, with average heatwave days increasing from 7.4 to 32.2 (Dasgupta et al., 2024). The human body's ability to adapt to climate is being put to the test more as the temperature rises, particularly for vulnerable groups. Among the manifestations of climate change, heat stress has arisen as a major concern, particularly in tropical regions such as India. In contrast to heatwaves, which are characterized by temperature thresholds, heat stress is a physiological reaction in which the body absorbs too much heat from metabolic or environmental sources, posing health risks when it cannot dissipate the heat (IPCC, 2022). Low wind speeds, high ambient temperatures, and high humidity all worsen heat stress, which affects thermoregulation of human body. Rising temperatures and more frequent extreme weather events are expected to contribute to a 1.5% increase in the average world heat stress by 2100, according to the IPCC (2023).

This study uses data on UTCI from the Copernicus Climate Change Service (1994–2024) to calculate the heat stress and its effects on rural women. In contrast to the Wet Bulb Globe Temperature (WBGT) – one of the often-used measure of heat stress in the literature, UTCI captures physiological reactions, including blood flow and sweating, by integrating air temperature, humidity, wind speed, mean radiant temperature, and clothing insulation (Foster et al., 2020).

While heat stress affects all groups, rural women between the ages of 15 and 35 experience physiological and socioeconomic difficulties necessitating a gender-specific focus. Long-term exposure to heat increases the risk of dehydration, heat-related disorders, and reproductive health difficulties for these women (Kjellstrom et al., 2009; Pogačar et al., 2019; Fatima et al., 2026). These hazards are made worse by socioeconomic variables such as restricted access to healthcare, education, and cooling infrastructure (Pradhan et al., 2013). The risks of dehydration and neonatal mortality are increased when heat stress combines with pregnancy and caregiving, posing additional difficulties for mothers (Purbey et al., 2024). In order to evaluate heat stress risk, this study uses data from the NFHS-4, 2015-16, concentrating on factors such as cooking fuel (which indicates indoor air pollution), place of delivery (which reflects access to medical care), and level of education among rural women.

This study conceptualizes risk as a function of exposure, vulnerability (sensitivity and adaptive capacity), and hazard (heat stress via UTCI), using the framework from the IPCC's AR5 in IPCC (2014). A woman's risk index for heat stress is created at state-level, which includes indicators of hazard (heat stress), adaptive capacity (e.g., media access, antenatal care), sensitivity (e.g., BMI, adolescent pregnancy), and exposure variables (e.g., solid fuel use for cooking, lack of safe and easy water access). The AR5 approach for heat risk assessment is rare in India and a recent district level study uses a broader set of indicators (Prabhu et al., 2025). This study addresses a critical research gap in gender-specific heat stress studies in India, particularly for rural women using the AR5 approach. A recent study that analyses women specific impact of heat uses a different methodology and the set of indicators vary from this study (Swaminathan et al., 2025). Further, this study contributes to the thin literature that integrates micro-level socio-economic data with macro-level spatial hazard information operationalizing IPCC's risk concept in a manner that captures both distributional heterogeneity and spatial hazard variation.

The rest of the paper is structured as follows: The next section provides a detailed summary of the relevant literature. The following section describes the research methodology adopted along with the data used for the analysis. The results are discussed in the next section, and the last section provides concluding observations.

LITERATURE REVIEW

While the present study specifically focusses on risk due to heat stress, the literature reviewed here is based on studies that covered heat stress, heat waves and rising heat episodes in general.

Regional and Climatic Variations in India

In low- and middle-income tropical countries, workers endure the most of increasing heat stress, a consequence of climate change that disproportionately affects these regions. Studies suggest that populations in tropical climates face the greatest risk of extreme heat exposure due to intense solar radiation and high humidity, which amplify heat stress effects (Xiang et al., 2014; Kjellstorm, 2009). Developing countries often lack sufficient adaptive capacity - the ability to adjust to heat stress, distinct from mitigation, which focuses on reducing heat stress - leading to greater occupational health risks compared to developed nations (Habibi et al., 2024). In India, this is particularly evident in rural areas, where limited access to cooling infrastructure exacerbates vulnerabilities for women engaged in labor-intensive work.

Urbanization trends further intensify heat stress in developing nations. Rapid urban expansion exposes growing populations to the urban heat island effect, where urban areas experience significantly higher temperatures than rural counterparts due to reduced moisture, heat-retaining materials, and altered land surfaces (Lundgren et al., 2012). In Indian cities, concrete buildings, asphalt roads, and tar-sealed infrastructure elevate ambient temperatures by several degrees, increasing health risks for urban and peri-urban workers (Kjellstorm, 2009; Kumar et al., 2022). Rural women, however, face unique challenges due to limited access to shade, water, and healthcare, compounding their heat stress exposure.

India’s vast geographical and climatic diversity results in pronounced regional variations in heat stress. The Tropic of Cancer divides the country into two climatic zones: southern states, which experience hotter and more humid conditions, and northern regions in the warm temperate zone (Kumar et al., 2022). For instance, Chennai, on the southeastern coast, faces high relative humidity, intensifying heat stress, while Delhi, with higher absolute temperatures but lower humidity, experiences slightly mitigated effects (Kumar et al., 2022). These variations highlight the interplay of temperature and humidity, particularly impacting rural women in humid southern states who work outdoors with minimal protective measures.

Heat waves, a recurring hazard in India, vary by region. Eastern coastal states are more prone to extreme heat waves, while northern India experiences prolonged fog conditions, which, though less related to heat stress, affect environmental and economic outcomes (Dash & Kjellstorm, 2011). Recent trends highlight the severity of heat episodes, with Delhi recording a mean maximum temperature of 41.4°C in May of 2025-1.5 °C above its historical average (Dasgupta et al., 2024). Rural women in central and eastern India, where heat waves and droughts are prevalent, face heightened risks due to prolonged exposure during agricultural tasks.

Cold waves dominate the north, storms and floods affect coastal areas, and heat waves, dry spells, and droughts prevail in central India (Dash & Kjellstorm, 2011). Temperature projections indicate a 2–4°C rise by century’s end in India (Krishnan et al., 2020). Following the tragic loss of approximately 2,500 lives in 2015, heat waves were recognized as natural disasters in India in 2016 (Venugopal et al., 2020). Beyond meteorology, regional disparities shape economic outcomes. Coastal regions benefit from trade opportunities, economic diversification, and better governance, while interior landlocked states face logistical and infrastructural challenges (Gallup et al., 1999). These disparities exacerbate heat stress impacts in rural areas, where women often lack access to resources like clean water or medical facilities, increasing their vulnerability to heat-related illnesses.

Occupational Heat Stress

Experimental studies in India reveal that workers in physically demanding sectors suffer significantly from heat-related health issues. In a glass manufacturing unit, high ambient temperatures lowered productivity, highlighting the need for improved working conditions and labour standards (Somanathan et al., 2021). The impact is especially severe in labour-intensive and informal sectors like agriculture and brick manufacturing, where rural women bear the brunt of productivity losses due to prolonged outdoor exposure.

India's unorganized workforce lacks adequate occupational health measures. Outdoor labour is widespread, but hygiene, safety, and thermal comfort regulations remain inadequate (Venugopal et al., 2015). Over half of the workers surveyed reported heat-induced productivity losses. Women working in brick kilns experienced a 1.8% drop in weekly productivity per degree rise in temperature, along with cardiac strain and slower walking speed (Sett & Sahu, 2014). Women aged 15–35 are most at risk due to limited access to rest breaks and protective clothing.

The COVID-19 pandemic introduced additional challenges, particularly with personal protective equipment (PPE). Fluid-resistant PPE restricts heat dissipation, leading to elevated body temperatures, excessive sweating, and thermal discomfort among healthcare and industrial workers (Foster et al., 2020). Globally, gender norms and socioeconomic status heighten exposure risks. In Gambia, pregnant women in subsistence farming faced reduced ability to cool effectively (Spencer et al., 2022). In the U.S., construction and agricultural workers often rely on coping strategies like hydration and shade (Uejio et al., 2017, 2018), but protective clothing often worsens heat stress (Borg et al., 2021) in outdoor occupations.

Occupational heat stress reduces work capacity, particularly for outdoor labourers in agriculture, mining, and construction. Health impacts include dehydration, fatigue, dizziness, and long-term risks like cardiovascular and kidney diseases (Lundgren et al., 2012; Habibi, 2021). Workers in India's automotive, coal mining, ceramics, textiles, and stone quarrying industries are especially vulnerable (Dash & Kjellstrom, 2011). By 2030, India may lose 34 million full-time jobs due to heat stress, half in agriculture (Dasgupta et al., 2024).

Beyond health, heat stress also affects labour markets. Lost work hours due to heat rose from $280 billion in 1995 to $311 billion in 2010, with projections reaching $2.4 trillion by 2030 (Borg et al., 2021). Agricultural workers are four times more likely to suffer heat-related illnesses, particularly in low-income countries (Xiang et al., 2014). Initiatives like the HEAT-SHIELD project (Habibi et al., 2024), offering real-time heat warnings, aim to mitigate these risks, but their reach in rural regions is limited.

India's caste hierarchy is strongly linked to occupations, with those lower in the social hierarchy are in occupations that are more exposed to heat stress and more so in rural areas (Shah et al., 2025).

Gender and Age Vulnerabilities

Accurately identifying workers at risk of heat stress is challenging due to variability in heat tolerance, influenced by environmental conditions, physical activity, and biological factors like age, gender, pregnancy, medical conditions, BMI, and physical intensity (Lucas et al., 2014; Kjellstrom et al., 2013; Habibi et al., 2015, 2024). Rural women aged 15-35 face unique risks due to physiological and socio-economic factors.

Gender differences in thermal regulation are pronounced under extreme heat. Women generally have lower aerobic capacity, leading to higher relative workloads for the same tasks as men (Sett and Sahu, 2014). Smaller blood volumes result in elevated heart rates during heat exposure (Mehnert et al., 2001). Men rely more on evaporative cooling through sweating, effective in hot-dry climates, while women dissipate heat via convection, better suited for hot-humid environments (Xiang et al., 2014; Habibi et al., 2024). However, women exhibit higher core and skin temperatures, elevated heart rates, and greater blood pressure during heat exposure, with lower maximal sweat rates limiting tolerance in arid conditions (Havenith, 2005). Reproductive hormones and menstrual cycles further influence temperature regulation, with women having colder distal skin temperatures (Lundgren et al., 2012). Studies using the Predicted Heat Strain (PHS) model show gender-based disparities in sweat rates under simulated heat conditions (Mehnert et al., 2001). These physiological differences place rural women, working long hours in direct sunlight, at heightened risk of heat-related illnesses.

Older individuals face greater risk stress due to lower metabolic rates and diminished aerobic capacity, often exacerbated by sedentary lifestyles (Lundgren et al., 2012). Elderly women, particularly in rural areas, face nearly double the mortality rates of men during heat waves, partly due to gender-specific physiological changes and longer life expectancies (Bogdanovic et al., 2013, as cited in Steen, 2018). Pregnancy introduces additional vulnerabilities, with increased blood volume, higher core temperatures, and hormonal fluctuations increasing heat stress susceptibility (Kjellstrom et al., 2013; Lundgren, 2013; Spencer et al., 2022; Habibi et al., 2024). Rural pregnant women, with limited access to shade or hydration, face elevated risks of dehydration and reproductive health complications. The empirical evidence emphasizes heat stress's disproportionate impact on rural Indian women, driven by regional climatic variations, occupational exposures, and physiological vulnerabilities. However, existing research often overlooks the unique socio-economic and gender-specific risks faced by this group.

Literature gap

Previous studies have examined how heat stress affects occupational health and productivity in low- and middle-income countries, including India (Xiang et al., 2014; Kjellstrom et al., 2009; Venugopal et al., 2020; Shah et al., 2025), and they also point out specific vulnerabilities related to region, gender, and age (Sett & Sahu, 2014; Spencer et al., 2022; Lundgren et al., 2012). Much of the existing research focuses on broad occupational categories such as agriculture and manufacturing or relies on controlled experimental settings (Somanathan et al., 2021; Foster et al., 2020). Limited studies address the risk faced by specific sub-groups like women in different age brackets. Furthermore, the IPCC AR5 risk framework, which includes exposure, vulnerability, and hazard, has been applied to heat stress in only one recent study (Prabhu et al., 2025). The AR5 approach for heat risk assessment remains rare in India. The recent district-level study by Prabhu et al. (2025) applies this framework but uses a broader set of indicators and does not focus specifically on rural women or a defined age group. Swaminathan et al. (2025), while women-specific in focus, adopts a different methodology and a different set of indicators, and does not integrate micro-level NFHS socio-economic data with macro-level spatial UTCI hazard information using the AR5 framework. This study therefore addresses these gaps by combining individual-level socio-economic characteristics from NFHS-4 with state-level heat stress hazard measured through UTCI, applying the AR5 risk framework with explicit gender- and age-specific focus on rural women aged 15–35.

RESEARCH METHODOLOGY

Methodology

This study employs the risk-based framework of the AR5 of the IPCC (2014) to assess the heat stress risk faced by rural women in India. This section first describes the UTCI as the primary heat stress metric, then outlines the IPCC conceptual framework, and finally details the construction of the composite index. The data sources used for the analysis are discussed subsequently.

Universal Thermal Climate Index

The UTCI is a widely recognized metric for assessing human thermal comfort. It accounts for human thermoregulation by considering air temperature, wind speed, mean radiant temperature, and humidity simultaneously (Foster et al., 2020; Kumar et al., 2022). UTCI is defined as the air temperature of a reference outdoor environment that would produce the same physiological response in the human body as the actual environment under study — including responses such as sweat production, shivering, skin wetness, and changes in blood circulation (Blazejczyk et al., 2012). Unlike other heat stress metrics such as the Heat Index or WBGT, UTCI integrates meteorological variables with a multi-node human thermoregulation model, making it more physiologically comprehensive (Foster et al., 2020).

Comparison of UTCI with Other Indices

Approximately 40 thermal comfort indices have been proposed and utilized globally (Blazejczyk et al., 2012). These indices are broadly categorized into three groups:

- Rational Indices: Based on heat balance equations, such as the Heat Stress Index (HSI) and Required Clothing Insulation (IREQ) for cold environments.
- Empirical Indices: Based on objective and subjective measures of physiological strain, exemplified by the Physiological Strain Index (PSI).
- Direct Indices: Based on direct environmental measurements, such as Apparent Temperature (AT) and Wet-Bulb Globe Temperature (WBGT).

Several heat stress indices have been developed for occupational and public health applications, including the WBGT (1950s, USA), the PHS model incorporated into ISO 9886, the Thermal Work Limit (TWL, Australia, 2002), the Humidex (Canada), and the UTCI (established by the European Union and WMO in 2009). The Heat Index (HI) combines air temperature and relative humidity to estimate perceived temperature, and is applicable for conditions above 20°C. The Humidex similarly reflects the combined effect of heat and humidity. Both these indices are simpler single-factor constructs compared to UTCI.

The WBGT index, widely used for heat stress assessments in occupational settings (Kjellstrom et al., 2009, 2013; Venugopal et al., 2015, 2020; Sett and Sahu, 2014), is derived from three temperature variables: air temperature in the shade (dry bulb temperature), globe temperature (representing radiant heat), and natural wet-bulb temperature (reflecting evaporative cooling under actual sun and wind exposure). While WBGT has the advantage of being grounded in direct environmental measurements, it does not adequately capture the additional physiological strain arising from restricted sweat evaporation under conditions of high humidity and low wind speed (Hyatt et al., 2010). This limitation is addressed by the UTCI, which integrates all four meteorological parameters within a thermoregulatory model, making it the preferred metric for this study.

IPCC Assessment Report Framework

The conceptual foundation of the risk index used in this study is drawn from the IPCC's successive assessment reports, specifically AR4 (2007) and AR5 (2013–2014). The IPCC defines vulnerability in AR4 as the degree to which geophysical, biological, and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change, including climate variability and extremes (IPCC, 2007, p. 783).

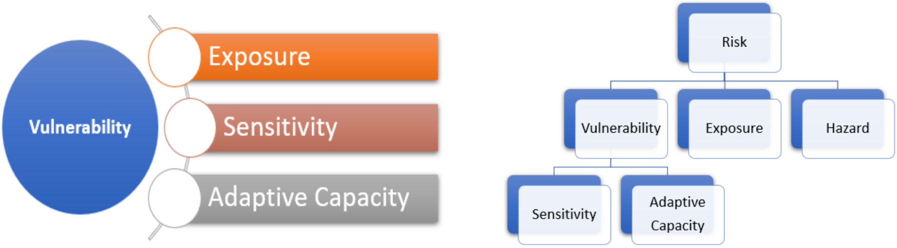
The Assessment Report 4, IPCC

The AR4 framework conceptualizes vulnerability as a function of three components: exposure, sensitivity, and adaptive capacity (Das et al., 2020). Exposure refers to the extent to which a system is subjected to climate-related stressors, while sensitivity determines how strongly the system responds to such exposure. A highly sensitive system may face severe consequences even under moderate climatic stress. However, adaptive capacity reflects the resources and mechanisms available to manage and cope with the problem. A community with strong adaptive capacity can reduce adverse outcomes despite high exposure and sensitivity (IPCC, 2007).

The Assessment Report 5, IPCC

Building upon the AR4 framework, AR5 shifts from a vulnerability-based approach to a risk-based framework, incorporating hazard, exposure, and vulnerability as key components (Das et al., 2020; Malakar et al., 2021). In this framework, hazard refers to potential climate-related events that could cause harm, while exposure remains the presence of people, assets, and ecosystems in areas affected by hazards. Vulnerability in AR5 is redefined to encompass sensitivity and adaptive capacity, emphasizing a system's predisposition to suffer adverse impacts (IPCC, 2014, p.1048). The risk-based approach integrates both socio-economic and environmental dimensions, facilitating a more comprehensive assessment of climate threats (Das et al., 2020; Singha et al., 2023). This study focused on constructing an AR-5 risk-based framework to understand the risks associated with rural women for Indian states.

Figure 1: Comparison of Vulnerability (AR4) and Risk (AR5) Frameworks



Index Construction

Based on the frameworks, the present study operationalizes the risk-based approach of AR5 (IPCC, 2014) by constructing a composite index that integrates hazard, sensitivity, adaptive capacity, exposure, and vulnerability components. To ensure a balanced assessment, equal weights are assigned to the indicators within each dimension. Heat stress, representing the hazard component, is quantified UTCI data, while sensitivity, adaptive capacity, and exposure are assessed through indicators from the NFHS. To standardize the data and for index construction, the dimensions are coded as binary variables, with values reflecting favorable or unfavorable conditions:

- Exposure Index: 1 = High exposure (unfavorable), 0 = Low exposure (favorable)
- Sensitivity Index: 1 = High sensitivity (unfavorable), 0 = Low sensitivity (favorable)
- Inverse Adaptive Capacity Index: 1 = Low adaptive capacity (unfavorable), 0 = High adaptive capacity (favorable)

With multiple indicators representing micro (individual/household) level information sourced from NFHS survey, the index calculations for exposure, sensitivity and adaptive capacity follow the standard approach employed in the literature on multidimensional deprivation (Alkire & Foster, 2011). The indices are first assessed at individual level and subsequently aggregated to state-level using appropriate weights for commensurability with the hazard index.

- Hazard Index: Quantified using fraction of heat stress exceedance days in a year, calculated as:
  Hazard Index = $X/365$
  where:
  - X = Number of days of heat stress exceedance for a given state in a year

This study employs a framework to assess heat stress risk from the methodology outlined in AR5 (IPCC, 2014). Following the AR5 risk framework, the Risk Index is computed using a multiplicative approach (Kc et al., 2020; Malakar et al., 2021) expressed as:

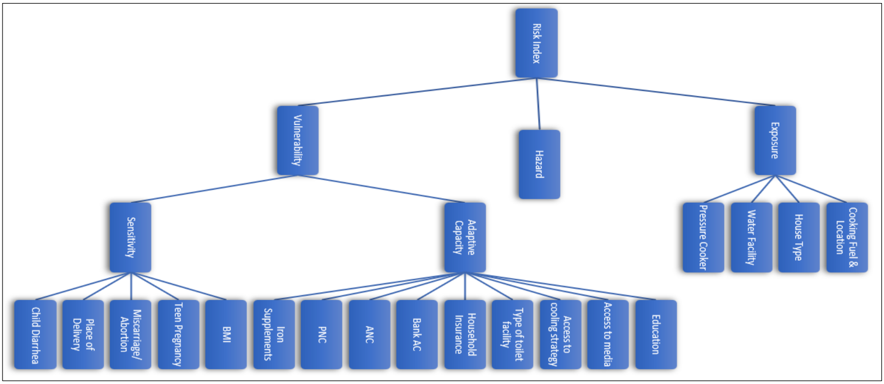
$$R = f(V, E, H) = V \times E \times H$$

where V is the Vulnerability Index (combining sensitivity and inverse adaptive capacity), E is the Exposure Index, and H is the Hazard Index. This multiplicative formulation ensures that risk is negligible when any one component is absent, and that high risk arises only when hazard, exposure, and vulnerability jointly co-occur, better reflecting the interactive nature of climate risk as conceptualized in AR5. Risk index close to zero indicates favourable conditions and close to one indicates higher risk for rural Indian women.

Figure 2 presents flow chart detailing the indicators selected for each dimension of risk: hazard, exposure, and vulnerability . In the figure, household indicators are classified as follows: house type is classified into pucca and other types; water facility as on the premises and others; toilet facility as modern or basic; and education level as no education, primary, and others. Health-related variables such as miscarriage, place of delivery, antenatal care (ANC), postnatal care

(PNC), iron supplement intake, child diarrhea, and teenage pregnancy are considered for women who were pregnant or gave birth within the past five years. Other indicators characterised as access to media, health insurance coverage, ownership of a bank account, and possession of a pressure cooker. Body Mass Index (BMI) is classified as normal if it falls within the range of 18.5 to 22.9 kg/m².

Figure 2: Heat Stress Risk: Dimensions and Indicators



Note: To calculate the respective indices, exposure indicators are weighted by a factor of 1/4, adaptive capacity indicators by 1/9, and sensitivity indicators by 1/5, yielding the Exposure Index, Adaptive Capacity Index, and Sensitivity Index.

Data and Sources

This study draws on two primary data sources: the UTCI, obtained from the Climate Data Store maintained by the European Centre for Medium-Range Weather Forecasts (ECMWF), and micro-level survey data from the NFHS-4. The two datasets are combined to construct a composite risk index following the AR5 framework of the IPCC (2014).

Universal Thermal Climate Index (UTCI) Data

The primary climate data used in this study is UTCI, sourced from the ERA5 Reanalysis dataset produced by the ECMWF through the

Copernicus Climate Change Service. The dataset was downloaded in NetCDF format — Network Common Data Form, a widely used file format in climate science for storing multidimensional variables such as temperature, humidity, and wind speed (. The raw data download covers India's geographical extent, bounded by the coordinates North: 37.25°, West: 68°, South: 6.75°, and East: 97.5°.

The downloaded files contain hourly UTCI values, originally recorded in Kelvin, and were converted to Celsius by subtracting 273.15 to make the values interpretable. The dataset spans 31 years, from 1994 to 2024, yielding approximately 11,325 NetCDF files in total (365 days/year × 31 years). The spatial resolution is 0.25° × 0.25°, where each grid cell represents an area of approximately 27.5 km by 27.5 km, allowing for a granular breakdown of thermal conditions across the Indian subcontinent. Time in the original dataset is recorded in Coordinated Universal Time (UTC), which ensures consistency across regions and eliminates discrepancies caused by local time zones.

To facilitate state-level analysis, state boundary shapefiles were requested and collected from the Survey of India's Online Maps Portal (Ministry of Science and Technology), following the submission of a user request form. Using these shapefiles, the latitude and longitude coordinates in the NetCDF files were matched to the corresponding state boundaries to extract state-wise UTCI values.

Data Processing and Aggregation

The original hourly UTCI data were aggregated sequentially into three temporal resolutions for analysis:

- Daily data: The hourly values were averaged to construct daily mean UTCI for each state, producing a daily time series from 1994 to 2024. These daily state-wise mean values were exported as CSV files.

- Monthly data: From the daily files, 372 monthly summary files (12 months × 31 years) were generated, capturing monthly trends in thermal comfort across states.
- Annual data: 31 annual summary files were constructed from the monthly data, providing yearly UTCI patterns for each state across the study period.

From the daily mean UTCI values, the study examined temporal patterns in heat stress through z-score analysis. Z-scores were calculated for specific reference years — 1994, 2015, and 2024 — as well as for two multi-year averages: 1994–1999 and 2020–2024. The z-scores are computed against each state's own 30-year mean, to capture relative departures from the long-run baseline at the state level. These z-score analyses and the broader patterns of thermal change are discussed in Poonguzhali et al. (2025). While the heat stress value has increased over the years across almost all months in most of the states in India, the increase has pushed a few regions in the Southern India into the 'moderate/strong heat stress' category

In addition to z-score analysis, two sets of summary tables were constructed to characterize heat stress patterns over time (these tables are provided in the appendix):

1. Overall average value of heat stress across all the years for each month (Table A1).
2. Number of days exceeding the monthly average of heat stress over different periods (Table A2).

Construction of the Hazard Index

As mentioned above, to construct the heat stress hazard index for the year 2015, corresponding to the NFHS-4 survey year, the study computed the number of days in 2015 during which UTCI values exceeded reference average thresholds. Based on the annual five-year average exceedance values for 2015, states were ranked from 1 (lowest number of exceedance days) to 35 (highest number of exceedance days). These values were then used to arrive at the final Hazard Index for each state:

$$\text{Hazard Index} = X/365 = \text{Number of Exceedance Days} / 365$$

where X is the number of heat stress exceedance days for a given state. This normalization scales the hazard values between 0 (lowest heat stress exceedance) and 1 (highest heat stress exceedance), ensuring comparability across states. This approach directly captures the fraction of the year under heat stress conditions for each state, preserving the absolute magnitude of heat stress.

National Family Health Survey (NFHS-4)

For examining the risk of women to heat stress, this study uses data from the NFHS-4, conducted in 2015–16. The NFHS is a large-scale, multi-round survey conducted across India covering health, nutrition, family welfare, and a range of socio-economic indicators. NFHS-4 data are publicly accessible through the website of the International Institute of Population Sciences (IIPS). While NFHS-5 data is also available for use, the data collection process was affected by COVID-19 pandemic related disruptions. Given this disruption and the need for temporal alignment with the 2015 UTCI reference year, this study uses NFHS-4 as the primary survey source.

The analysis is restricted to rural areas and to women aged 15–35. This sample is the primary focus of the study, as women in rural areas are likely to face greater heat exposure owing to their occupational and domestic activities, combined with limited access to infrastructure and higher rates of poverty. The age group 15–35 encompasses both the adolescent and early motherhood phases. Analyzing the risk of this group can set a benchmark for broader population subgroups, given the potential life-cycle effects from pre-motherhood through to early childhood and beyond.

To ensure the robustness of the findings, the study conducted checks across three sample specifications:

- Baseline analysis: Full rural sample of women aged 15–49 years.
- Rural areas: Only the rural sample, aged 15–49 years.
- Rural and age-specific: Restricted to rural women aged 15–35 (primary sample).

Data Preparation and Merging

The NFHS-4 data are distributed across multiple unit-level files, of which this study utilizes two: the Household Recode (HR) file containing household-level information and the Individual Recode (IR) file containing individual-level data for women. To construct the dataset, relevant variables were extracted from both files and merged using a common key based on the cluster number and household number. The final dataset incorporates both household- and individual-level characteristics.

Household-level variables include housing conditions, access to water and sanitation facilities, media exposure, bank account ownership, and possession of assets such as a pressure cooker. Individual-level variables include educational attainment, body mass index (BMI), health insurance coverage, and reproductive and child health outcomes such as miscarriage, place of delivery, antenatal and postnatal care visits, iron supplement intake, incidence of child diarrhea, and teenage pregnancy. Health-related variables pertaining to pregnancy and delivery are restricted to women who reported a birth or pregnancy within the five years preceding the survey. Table A3 provides an overview of the definitions used for various indicators used to capture exposure, sensitivity and adaptive capacity of rural women in India, and Table A4 provide summary statistics corresponding to the indicators.

RESULTS

Results and Discussion

The index values for exposure, sensitivity, adaptive capacity, vulnerability, number of days heat exceedance (compared to the overall five-year average), heat stress as a hazard, and the AR5 Risk framework are calculated. For index construction, indicators are coded as binary variables - where 0 indicates a favorable condition and 1 indicates an unfavorable condition for most dimensions, with the exception of adaptive capacity, where the coding is reversed (1 = favorable).

State-level comparison

Table 1 presents state-level rankings derived from these index values, with ranks running from 1 (most favorable) to 34 (least favorable), allowing comparison of relative heat stress risk positions across states. Jharkhand tops the list of the AR5 Risk index with a rank of 34 (Table 1), reflecting a high risk of heat stress for rural women. Its exposure index rank of 34 depicts distance to water location and house type, drives the heat exposure for rural women (Kjellstrom et al., 2013) with a heat stress rank of 19. Its sensitivity index rank of 31 indicates highly sensitive to risks, and the adaptive capacity index rank of 3 suggests very limited coping mechanisms, such as low education, improper cooling mechanism access (Pradhan et al., 2013), and a smaller number of people having health insurance. The number of heat stress exceedance days also drives risk alongside all these factors. Bihar closely follows Jharkhand (rank 33). It reflects challenges like reproductive health risks (Purbey et al., 2024), such as miscarriage and place of delivery in sensitivity, along with high exposure driven by housing type and access to pressure cooker, which increases the risk for rural women. Madhya Pradesh (rank 32) and Odisha (rank 29) also rank poorly, following these two states because of high exposure, moderate sensitivity, and limited coping mechanisms.

In contrast, some of the states exhibit favorable outcomes with lower risk index values and better rankings. Sikkim ranks 6 in the risk index, reflecting low heat stress risks. Its sensitivity index ranks 1, which is among the lowest, and its exposure index ranks 6. Its adaptive capacity is moderate and ranks 19 because of a lack of cooling mechanisms (Spencer et al., 2022; Kjellstrom et al., 2013) and a lack of health insurance. Himachal Pradesh ranks 9; its sensitivity ranks are moderate, but the adaptive capacity index depicts stronger resilience. The state's low heat stress rank of 1 further reduces risk. In southern states, Kerala has a rank of 3. Despite the high hazard of heat stress, where it ranks 31, its exposure index (rank 4), sensitivity (rank 5), and adaptive capacity (rank 34) are highly favorable, driven by high education levels.

Table 1: State-wise Rank Order of Heat Stress Risk and Its Sub-Component Indices

	Index Type					
State	**Exposure**	**Sensitivity**	**Adaptive Capacity**	**Vulner-ability**	**Heat Stress**	**Risk**
Andaman & Nicobar	12	6	28	7	14	10
Andhra Pradesh	19	20	27	9	32	16
Arunachal Pradesh	20	26	6	29	6	21
Assam	27	23	10	25	7	23
Bihar	28	27	1	33	26	33
Chandigarh	3	34	32	17	10	4
Chhattisgarh	33	21	17	18	16	28
Daman and Diu & Dadra and Nagar Haveli	2	2	25	4	30	1
Delhi	1	32	24	19	13	2
Goa	5	3	33	2	34	5
Gujarat	15	16	14	21	33	18
Haryana	11	10	20	14	12	12
Himachal Pradesh	9	18	26	10	1	9
Jammu and Kashmir	10	13	13	22	3	13
Jharkhand	34	31	3	32	19	34
Karnataka	18	4	16	13	4	15
Kerala	4	5	34	1	31	3
Madhya Pradesh	30	17	5	30	22	32
Maharashtra	16	15	18	15	27	17
Manipur	22	29	11	27	11	22
Meghalaya	26	24	8	28	15	26
Mizoram	17	14	9	23	24	20
Nagaland	23	33	2	34	5	30
Odisha	32	12	15	20	28	29
Puducherry	8	9	30	6	20	8
Punjab	7	7	29	5	9	7
Rajasthan	24	11	7	26	21	25
Sikkim	6	1	19	8	2	6
Tamilnadu	13	8	31	3	29	11
Telengana	21	22	23	12	23	19
Tripura	31	19	22	11	18	24
Uttar Pradesh	25	30	4	31	17	31
Uttarakhand	14	25	12	24	8	14
West Bengal	29	28	21	16	25	27

Source: Author's Calculation

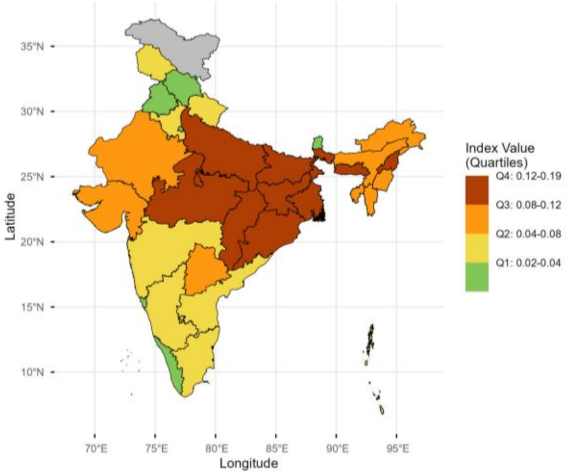
Note: (1) Exp-Exposure Index; Sens-Sensitivity Index; AdapC-Adaptive Capacity Index; Vuln-Vulnerability Index; HtStr-Heat Stress. (2) The ranking values low to high based on the respective index values. For adaptive capacity, the rankings are in the reverse order from high to low

Regional Patterns

Northern states like Himachal Pradesh (rank 9), Sikkim (rank 6), and Jammu and Kashmir (rank 13) show lower risks due to cooler climate conditions and moderate exposure. However, Punjab (rank 7) and Haryana (rank 12) face higher exposure, though their adaptive capacity helps reduce risks, and these states maintain low vulnerability. Southern states like Kerala (rank 3) and Tamil Nadu (rank 11) benefit from strong adaptive capacity but face high hazard levels. Andhra Pradesh (rank 16) and Telangana (rank 19) show higher exposure reflecting humid conditions (Kumar et al., 2022). Western states like Gujarat (rank 18) and Maharashtra (rank 17) depict mixed outcomes in the dimensions. Gujarat's exposure index rank of 15 and heat stress rank of 33 indicate significant risks, while Maharashtra's moderate indices suggest a reasonable coping mechanism.

Interaction between exposure, sensitivity, adaptive capacity, and hazard gives mixed outcomes. Jharkhand and Bihar rank high despite a moderate sensitivity index, because their high exposure and low adaptive capacity increased their risk towards heat stress for women. Despite high heat stress, Kerala has high adaptive capacity levels, keeping the overall heat stress risk lower.

Figure 3: Heat Stress Risk Index Map for India



Source: Author's Calculation.

The heat stress risk index map (Figure 3) portrays a spatially differentiated picture of heat stress risk faced by rural women across India. Figure B1 in Appendix B similar quartile maps for the sub-components of risk – viz., heat stress hazard, exposure and vulnerability.

States in central and eastern India constitute the highest risk zone. Madhya Pradesh, Chhattisgarh, Jharkhand, Odisha, and Bihar fall in the fourth quartile (Q4: 0.12–0.19), shaded in dark brown, reflecting a convergence of high heat stress hazard, elevated sensitivity, and limited adaptive capacity among rural women in these states. These states are characterized by high shares of women engaged in outdoor agricultural labour, poor housing conditions, and constrained access to health and social infrastructure, all of which amplify risk when combined with persistent heat stress.

The third quartile (Q3: 0.08–0.12), shown in orange, covers a broad set state including Rajasthan, Gujarat, Uttar Pradesh, and parts of the northeast. While Rajasthan and Gujarat face intense dry heat, their placement in Q3 rather than Q4 suggests that vulnerability dimensions partially moderate overall risk relative to the central Indian states. The northeastern states in this quartile face compounding risks from humid heat combined with moderate levels of social vulnerability.

Southern states - including Tamil Nadu, Andhra Pradesh, Telangana, and Karnataka - fall within the second quartile (Q2: 0.04–0.08). Despite facing humid and high-temperature conditions, their relatively better performance on adaptive capacity indicators, tempers the overall risk score. Kerala, consistent with its strong human development profile, remains in Q1, with high adaptive capacity offsetting its non-negligible hazard and exposure.

Northern and northeastern hill states, including Himachal Pradesh, Uttarakhand, and Sikkim, occupy the first quartile (Q1: 0.02–0.04), depicted in green and yellow green, reflecting both lower thermal stress and comparatively better socio-economic conditions. Jammu and Kashmir remains unclassified due to data constraints. The spatial pattern underscores that the burden of heat stress risk is concentrated in the already disadvantaged central and eastern Indian states.

SUMMARY AND CONCLUSION

This study provides an analysis of heat stress risk for Indian rural women aged between 15 and 35. This study contributes by integrating micro-level socio-economic data sourced from NFHS-4 with macro-level spatial hazard information on heat stress measured using UTCI, and operationalizing IPCC’s risk concept in a manner that captures both distributional heterogeneity and spatial hazard variation. To capture the multifaceted aspects of heat stress, this study adopted an index based approach. The findings emphasize the regional disparities in heat stress risk for women.

Results suggest that rural women in Jharkhand, Madhya Pradesh and Bihar face the highest risk, driven by high exposure, moderate sensitivity, and limited adaptive capacity. In contrast, Sikkim and Himachal Pradesh exhibit low risk due to lesser heat stress from cooler climatic conditions and moderate adaptive capacity. Southern states like Kerala and Tamil Nadu, despite experiencing high heat stress, show lower risk due to better coping mechanisms compared to the central states.

The main contributions of this study include operationalizing IPCC's risk assessment by combining micro and macro level data, and explicit gender-specific focus and examination of how heat stress affects the physiological and socioeconomic challenges for rural women. By plotting state-level vulnerabilities and risks using choropleth maps, the study visually represents regional disparities. The findings align with India's National Action Plan on Climate Change, emphasizing the need for gender-sensitive interventions, such as improving access to cooling infrastructure, healthcare, and education in high-risk states.

The differences in the underlying framework, year of the data and methodology used does not lend to a direct comparison of the results from this study with Prabhu et al., (2025) or Swaminathan et al. (2025). Future research can be based on more recent data on socio-economic variables and analyzing changing heat stress risk patterns among Indian states. Further, future work can capture hazard (viz., heat stress) at a more granular level by overlaying the gridded UTCI data on the geo-coded NFHS data using the AR5 framework. Such assessment could not only provide a more accurate assessment of risk but also enable identification of targeted risk management policies.

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APPENDIX - A

Table A1: Overall Average Value of Heat Stress Across All the Years for Each Month

Month	Mean Heat Stress (in ºC)
Jan	14.2
Feb	16.6
Mar	20.8
Apr	24.9
May	27.5
June	27.7
July	26.7
Aug	26.5
Sep	26.0
Oct	23.4
Nov	19.0
Dec	15.2

Note. Using UTCI dataset published by Climate Data Store using overall average value calculated from 1994-2024 across all years for each month.

Table A2: Number of Days Heat Stress Exceeding The Monthly Average Values: 1994-2004, 2005-2014, and 2014-2024

Month	1994-2004	2005-2014	2015-2024
January	121	150	188
February	119	158	153
March	143	169	162
April	157	154	161
May	134	174	158
June	120	159	190
July	144	130	187
August	118	139	200
September	132	125	202
October	127	161	186
November	124	138	178
December	123	153	182

Note. Using UTCI dataset published by Climate Data Store using overall average value (Table A1) calculated from 1994-2024 across all the months.

Table A3: Definition of Indicators Used In The Index Construction

Indicator	Definition	Reference
Exposure Index		
Cooking Location & Fuel	0 = clean fuel; 1 = polluting fuel — captures exposure to indoor air pollution; 0 = indoor; 1 = outdoor/separate — indicates cooking environment conditions	Kjellstrom et al., 2013
Water Location	0 = on premises; 1 = off premises — reflects effort and exposure in water collection	Pogačar et al., 2019
Pressure Cooker	0 = has; 1 = does not have — indicates cooking exposure duration	Pradhan et al., 2013
House Type	0 = pucca; 1 = semi/kachcha — reflects housing quality and environmental exposure	Kjellstorm, 2009; Kumar et al., 2022
Sensitivity Index		
Body Mass Index	0 = 18.5–22.9 (normal); 1 = otherwise (under/overweight)- indicates nutritional vulnerability	Xiang et al., 2014; Kuehn & McCormick, 2017
Teenage Pregnancy	0 = no; 1 = age 15–19 at pregnancy/birth (last 5 yrs)— reflects early-age reproductive risk	Purbey et al., 2024
Miscarriage	0 = no; 1 = yes — indicates adverse reproductive outcome	Spencer et al., 2022
Place of delivery	0 = institutional; 1 = non-institutional — reflects access to safe delivery care	Purbey et al., 2024
Child Diarrhea	0 = no; 1 = yes — indicates child health vulnerability	Hyatt et al., 2010
Inverse Adaptive Capacity Index		
Education	0 = secondary+; 1 = no/primary — reflects knowledge and awareness level	Lundgren et al., 2013; Pradhan et al., 2013
Access to media	0 = access; 1 = no access — indicates information accessibility	Kjellstrom et al., 2013
Cooling Mechanism	0 = has fan/AC; 1 = none — reflects ability to cope with heat	Spencer et al., 2022; Kjellstorm et al., 2013
Toilet Facility	0 = improved; 1 = unimproved/none — indicates sanitation condition	Sett and Sahu., 2014
Health Insurance	0 = yes; 1 = no — reflects financial protection for health	Venugopal et al., 2015
Bank Account	0 = has; 1 = no — indicates financial inclusion	Pradhan et al., 2013
ANC	0 = 4+ visits; 1 = <4 — reflects adequacy of antenatal care	Purbey et al., 2024
PNC	0 = yes; 1 = no/don't know — indicates postnatal care access	Purbey et al., 2024
Iron Supplements	0 = yes; 1 = no/don't know — reflects maternal nutrition care	Purbey et al., 2024

Note: In the table where the values are closer to 0 indicate better outcomes and closer to 1 indicate worse outcomes.

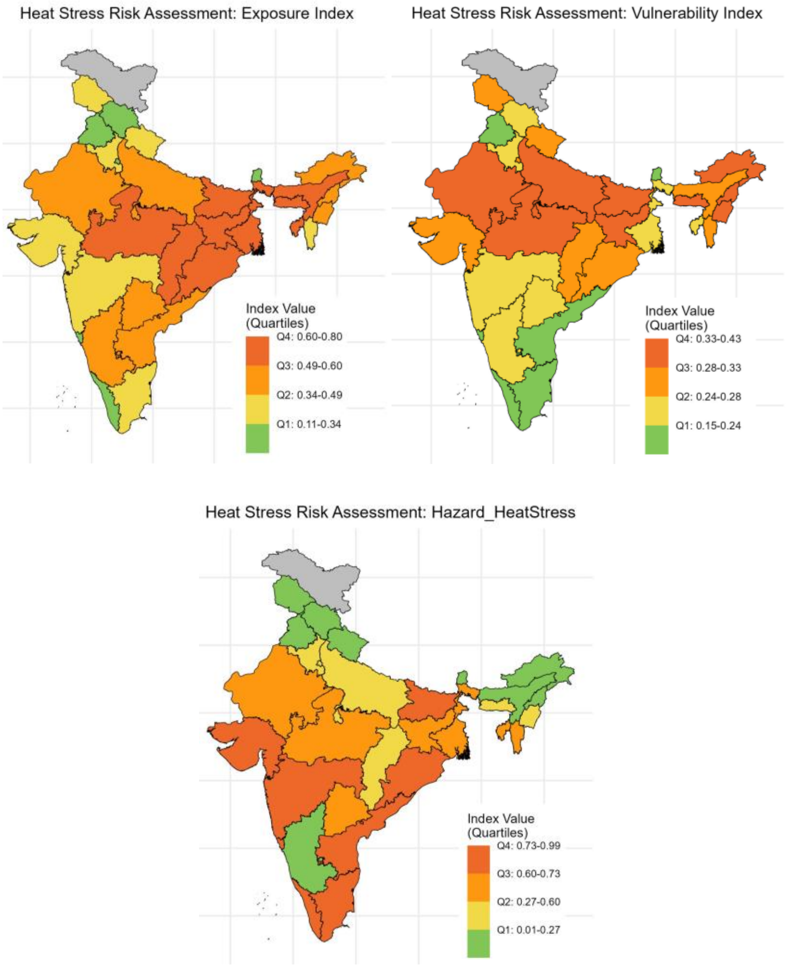
Table A4: Summary of Indicators Used In The Index Construction

Exposure Index		
Indicator	**0 (low)**	**1 (High)**
Cooking Location & Fuel	37.06	62.94
Water Location	66.28	33.72
Pressure Cooker	60.93	39.07
House Type	49.87	50.13
Sensitivity Index		
Variables	**0 (low)**	**1 (High)**
Body Mass Index	45.39	54.61
Teenage Pregnancy	88.11	11.89
Miscarriage	84.68	15.32
Place of delivery	74.45	25.55
Child Diarrhea	91.87	8.13
Adaptive Capacity Index		
Variables	**0 (High)**	**1 (Low)**
Education	59.29	40.71
Access to media	95.06	4.94
Cooling Mechanism	73.49	26.51
Toilet Facility	57.61	42.39
Health Insurance	17.86	82.14
Bank Account	91.06	8.94
ANC	47.23	52.77
PNC	35.02	64.98
Iron Supplements	76.27	23.73

Note: In the table where the values are closer to 0 indicate better outcomes and closer to 1 indicate worse outcomes.

APPENDIX - B

Figure B1: Maps of sub-components of Heat Stress Risk Index, India



Note: Green depicts better outcomes and Red depicts worst outcomes in each dimension.

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* Working papers are downloadable from MSE website http://www.mse.ac.in