Urban heat stress and perceived health impacts in major cities of Bangladesh

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Abstract

Urban heatwaves are a growing concern, especially in South Asian countries grappling with rapid urbanization and limited resources. While prior studies focused on the biophysical aspects of urban heat islands in this region, there is limited evidence of people's understanding of urban heat stress and its health consequences. This study aimed to investigate the perceived urban heat risk and associated health impacts in Bangladesh. A cross-sectional study involving 898 participants from eight major cities in Bangladesh were included in the study. A substantial proportion of individuals regularly experienced urban heat stress but have limited awareness of heatwave reduction measures. Moreover, perceived physiological impacts were found to be more severe than psychological impacts. Urban heat also moderately affected daily activities, particularly transportation, and sleep/rest. Factors like gender, home cooling systems, and spending time outdoors intensified heat's physiological and psychological impacts, while students, highly educated individuals, residents of traditional *katcha* houses, and those in good health experienced milder effects. Furthermore, individuals over 30 years of age and employed individuals exhibited greater knowledge about heat impact reduction but less affected by psychological impacts. These findings can inform targeted interventions and guidelines for heat mitigation and adaptation in South Asian cities.

Keywords: Urban heat stress; Heat adaptation; Climate mitigation; Human health; Heat resilient cities; South Asia

1. Introduction

Urbanization has rapidly transformed the global landscape, redefining where and how people live. Over half of the world's population now resides in urban areas, and an estimated 60% of the global population is expected to call cities home by 2030(United Nations, Department of Economic and Social Affairs, Population Division, 2018). However, this urban shift has a significant environmental cost, with cities consuming over two-thirds of global energy and contributing 70% of carbon emissions, intensifying climate change(C40 Cities, 2020). Amid the complex morphologies and human activities that define urban landscapes, another climate phenomenon looms large— the Urban Heat Island (UHI) effect, characterized by hotter microclimates and compromised thermal comfort for urban residents(Sun *et al.*, 2018; Xu *et al.*, 2018). The UHI effect is primarily caused by the presence of pavement structures in cities, which intensify daytime temperatures through heat absorption and release at night(Zhang *et al.*, 2021), while secondary contributions stem from waste heat generated by energy consumption, transportation, and various human activities(Shahmohamadi *et al.*, 2011). This phenomenon poses multifaceted challenges, affecting public health, escalating energy demands, and influencing urban livability.

Exposure to heat has been associated with a range of adverse health effects, including skin irritation, excessive sweating, respiratory illness, heat stroke and increasing heart rate and blood pressure, resulting in cardiovascular disease(Campbell-Lendrum and Corvalán, 2007; Cheng and Su, 2010). Heat exposure can also cause psychological impacts on individuals, especially vulnerable populations (e.g., elderly, children, pregnant women, workers, and people with pre-existing mental illness), such as increasing stress, reducing quality of life, cognitive impairment, and lowering mental health conditions(Kenney, Craighead and Alexander, 2014; Xu *et al.*, 2014; Zhang, Chen and Chen, 2023). Further, prolonged extreme heat events directly affect the daily functioning of people, inducing fatigue, discomfort, heat exhaustion, heat cramps, and heat strokes(Rajib *et al.*, 2011). Excessive urban heat also has profound implications for worker productivity and national economies. For instance, Australia suffered a $6.2 billion economic loss in 2014, equivalent to 0.33–0.47% of its GDP, due to workers reducing labor hours to cope with heat-induced stress(Zander *et al.*, 2015). These consequences will increase in the future with increasing urbanization and population burden(Heaviside, Macintyre and Vardoulakis, 2017).

The South Asia region, characterized by its complex geography and rapidly growing population, faces a formidable heat challenge. The region has experienced higher average temperatures than many other parts of the world, rendering it particularly susceptible to heat impacts(Sharma, Andhikaputra and Wang, 2022). Projections indicated a significant 1.6°C (2.9°F) temperature increase by 2050, leading to more frequent and severe heat waves in the region(Mani *et al.*, 2018; Masson-Delmotte, Zhai and Pirani, 2021). Recent years have witnessed devastating heat waves in countries like India, Pakistan, and Afghanistan, resulting in substantial damage. In 2015, one of the deadliest heat waves on record affected India and Pakistan, claiming around 3,500 lives(Im, Pal and Eltahir, 2017). In 2015, over 65,000 people were hospitalized in Karachi only for treatment of heat stroke(Glum, 2015).

Bangladesh is one of the most densely populated countries in South Asia, facing severe temperature rise due to rapid urbanization and population explosion. Over the last 30 years, the population has surged by 1.36% to 5.18%(Panday, 2020). Research indicates that Bangladesh has experienced a 0.5°C temperature increase in the last century, with an annual average temperature surge of 0.3°C over the past two decades compared to the 1895-1980 period(Tanvir, Humayain and Mahmud, 2019; Ripon and Al-Mamun, 2020).

Looking ahead, projections suggest that intense heatwaves will be more frequent at the end of the 21st century in South Asia and other parts of the world(Lhotka, Kyselý and Farda, 2018; Saeed, Schleussner and Ashfaq, 2021). Efforts to mitigate UHI and address climate change are vital to achieving the United Nations Sustainable Development Goals for sustainable cities and communities (SDG-11)(United Nations, 2019). To tackle such challenges, various strategies have been proposed and tested in cities worldwide to mitigate heat waves, with a focus on nature-based solutions, including green infrastructure(Coma *et al.*, 2017), and blue infrastructure(Driver and Mankikar, 2021; Siehr, Sun and Aranda Nucamendi, 2022); common engineered solutions such as cool(Rawat and Singh, 2022) and permeable materials(Wang *et al.*, 2019), urban design for ventilation(He, Ding and Prasad, 2020), and radiation regulation(Elgheznawy and Eltarabily, 2021) to increase latent heat flux and decrease temperatures. Evidence for such mitigation approaches is based on field measurements, numerical estimations or remote sensing observations. Such techniques lack the behavioral, economic and environmental adaptation that is required to cope with heat-related risks(Hajat, O'Connor and Kosatsky, 2010; Dare, 2019)

Promoting urban heat adaptation is also contingent on increasing public awareness and knowledge, empowering individuals to shield themselves from the adverse effects of heat proactively. Consequently, concerted efforts should be directed toward educating the populace about the impacts of urban heat and feasible adaptation strategies(He *et al.*, 2022). Heat waves have had devastating consequences, as evidenced by the recorded deaths of over 70,000 individuals in Western Europe in 2003 and approximately 15,000 deaths in Russia in 2009(Robine *et al.*, 2008; Dole *et al.*, 2011). Epidemiological studies have found a 4.5% increase in mortality risk for every 1°C increase in heat wave intensity and a 0.38% increase for every 1-day increase in heat wave duration in the United States(Brooke Anderson and Bell, 2011). Although the heat-related illness is preventable, it can be fatal if not addressed promptly(Roberts *et al.*, 2021). Mortality rates may increase by 31.3% with an increase of 1^{o}C in the global thermal climate index, and these increasing rates may be particularly pronounced in Bangladesh(Burkart *et al.*, 2014). Thus, understanding the impact of urban heat on residents is crucial for comprehending their vulnerability, awareness, and knowledge related to urban heat reduction. This information can inform evidence-based local policies, fostering bottom-up urban heat mitigation and adaptation efforts.

Despite some studies examining the perceptions of UHI mitigation and adaptation strategies in regions like China(He *et al.*, 2021, 2022), Japan(Kondo *et al.*, 2021), Germany(Beckmann and Hiete, 2020), and the USA(Howe *et al.*, 2019; Wang *et al.*, 2021), there is limited evidence from South Asia. Existing studies from Pakistan(Rauf *et al.*, 2017) and Bangladesh(Tawsif, Alam and Al-Maruf, 2022) primarily focused on household adaptation behavior to urban heat. However, such studies have limitations in providing a comprehensive understanding of urban heat impact, awareness, knowledge, and the sociodemographic factors influencing these aspects and their role in shaping local policies and regulations.

In the current study, we attempt to address these gaps by assessing (1) risk perception, knowledge levels, and health consequences of UHI and (2) the influence of sociodemographic variables on UHI impacts in Bangladesh. Our findings aim to offer a better understanding of individuals' vulnerability to extreme heat and awareness of strategies to mitigate impacts. This study is distinctive from prior efforts due to its in-depth exploration of heat-related perception and impacts, encompassing daily functions, knowledge, awareness, and physiological and psychological health. We hope the findings will inform policymakers and aid in the development of a Heat Adaptation Plan (HAP) to mitigate UHI, contributing to the achievement of Sustainable Development Goal 11, which focuses on creating sustainable cities and communities in Bangladesh and beyond.

2. Methodology

2.1. Study area

The study was conducted in Bangladesh, a rapidly developing country in South Asia (Raihan et al., 2022). The country is characterized by a tropical monsoon climate with three distinct seasons: hot summer (March to early June), rainy season (June to early October), and dry winter (mid-October to late February). However, climatic conditions vary across the country. During the hot summer, temperatures range from 23.0 to 25.8 ºC on average, with peaks reaching 31.3 to 35.3 ºC (Nissan et al., 2017). The current study was conducted on eight divisional cities of Bangladesh (Figure 1). These cities were selected to represent diverse geographic regions and demographic characteristics, encompassing coastal and inland areas, hilly terrains, commercial centers, and regions with significant migration and population growth.

The study area experiences a wide range of temperatures throughout the year. Winter temperatures average around 17 ºC in the northwestern and northeastern regions, while the coastal areas are slightly warmer, ranging from 20 ºC to 21 ºC (Abdullah et al., 2022). Notably, the urban heat island effect has a significant impact on temperatures, particularly in Dhaka city, where variations can be substantial, ranging from 2.5 ºC to 7.5 ºC (Tariq, 2022). Heat waves are most prevalent between April and June, peaking in May and occasionally extending into the monsoon season until September (Nissan et al., 2017). Relative humidity follows a similar pattern, peaking at around 90% during the early stages of the monsoon season and gradually decreasing towards the end of the rainy season, following the peak in maximum temperature (Nissan et al., 2017).

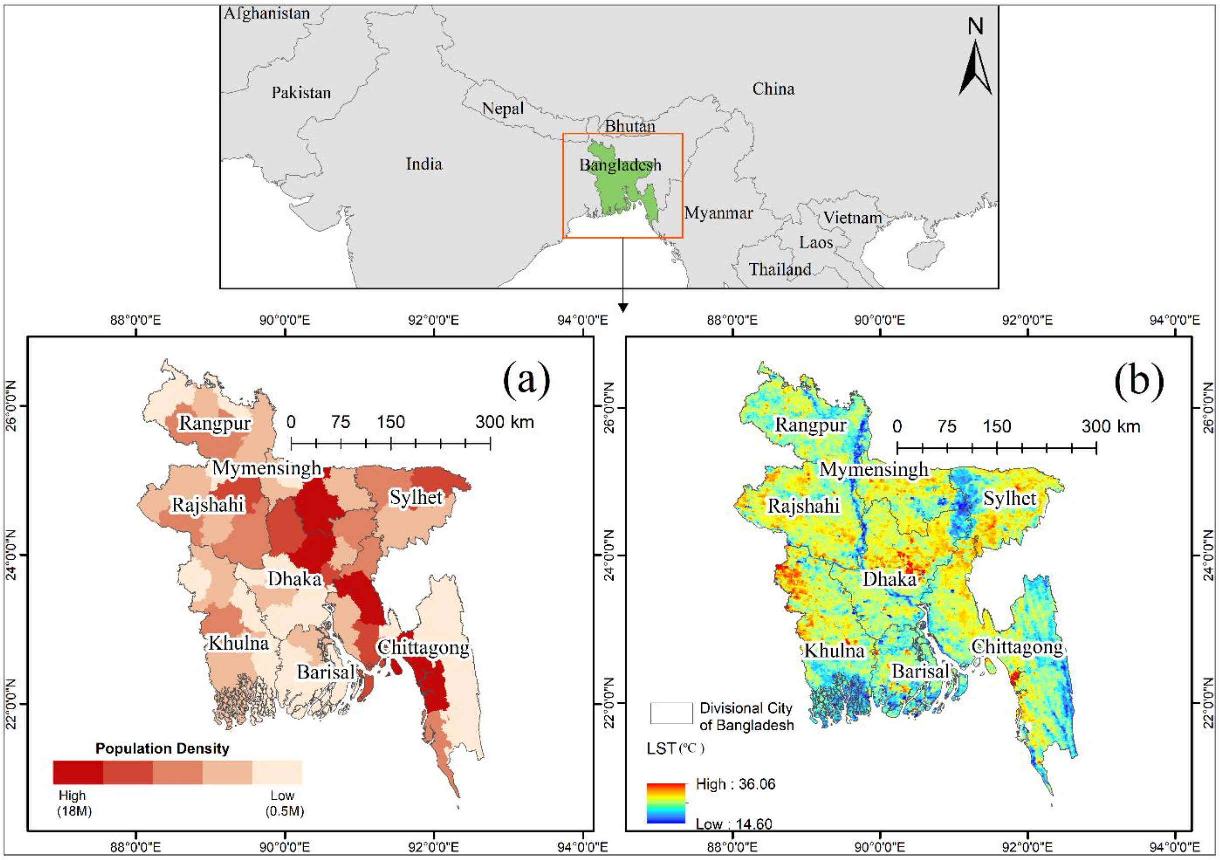


Figure 1. Study area location with (a) division wise population density (per sq km) and (b) Land Surface Temperature (LST), August-October, 2022 in Bangladesh.

2.2. Study design

We conducted an online cross-sectional study in Bangladesh from September 10, 2022, to October 15, 2022, to examine the impact of urban heat on health. This timeframe was chosen to coincide with the occurrence of heat waves in Bangladesh until September-October, allowing respondents to easily recall and relate to the effects and issues associated with metropolitan heat waves during this period.

The study inclusion criteria were those aged 18 years and above residing in the eight divisional cities of Bangladesh. A snowball sampling method was employed to select participants. We used a structured questionnaire distributed through multiple social media platforms, including Facebook, WhatsApp, Email, LinkedIn, and Instagram, utilizing an online Google form for data collection.

All participants provided electronic consent before taking the survey and were allowed to stop the survey at any time. The survey did not require disclosing personal information such as names or email addresses. The study was approved by the research ethical clearance committee of Khulna University, Bangladesh (KUECC-2022/09/32).

2.3. Questionnaire design

We aimed to assess the knowledge, perception, and health impacts of urban heat islands using a questionnaire divided into several sections. The first section focused on demographic and living conditions-related questions. It aimed to gather information about the respondents' demographic characteristics, such as gender, age, education, occupation, number of family members, monthly income, and perceived health condition. Additionally, this section inquired about housing patterns, perceived proximity to green spaces, time spent outdoors, and the presence of cooling systems in their homes to understand their living conditions more comprehensively.

The second section focused on examining the impacts of urban heat. It consisted of three questions to evaluate the perceived experience of urban heat stress and the severity of both physiological and psychological impacts of urban heat. The first question assessed the respondents' perception of urban heat stress by asking, "Thinking about your local area, do you ever feel stressed by the heat during the hot summers in Bangladesh?" The responses were recorded using a five-point Likert scale, ranging from 0 (not at all) to 4 (yes, very often). The second and third questions measured the perceived severity of physiological and psychological impacts of urban heat, respectively. Respondents were asked to rate the severity on a five-point Likert scale, ranging from 1 (none) to 5 (extra severe).

The third section of the questionnaire focused on exploring the symptoms of physiological and psychological illnesses associated with urban heat stress. Participants were asked about their experiences with a range of possible physiological illnesses caused by heat, which were in line with the illnesses identified by the World Health Organization (WHO). These included respiratory diseases (e.g., bronchitis, asthma), digestive system diseases (e.g., dyspepsia), skin heat damage (e.g., dermatitis), cardiovascular diseases (e.g., rapid heartbeat, high blood pressure, coronary heart disease), eye illnesses (e.g., conjunctivitis), metabolic diseases (e.g., diabetes), and urinary system illnesses (e.g., kidney function illnesses). Additionally, participants were asked about psychological illnesses, such as emotional irritability, difficulty controlling temper, low mood, decline of memory, insomnia, trouble concentrating, lack of interest, and poor appetite. Participants were requested to indicate any symptoms of physiological and psychological illnesses they may have experienced.

The heat-related impact on participant's daily life was assessed using five categories: going outside (e.g., how often and how long), working or studying (e.g., how efficiently), traveling (e.g., the mode, the amount of time, and frequency), sleeping or resting (e.g., how long, how often, and period), and diet (e.g., appetite, frequency). Respondents were asked to assess these questions on a five-point Likert scale ranging from 1 (none) to 5 (extra severe).

Respondent's knowledge and personal intention to address urban heat challenges were assessed using two questions. The first aimed to determine their intention to address the issue of urban heat and was measured using a five-point Likert scale ranging from 0 (not at all) to (4) extremely important). The second question aimed to understand their knowledge and understanding of strategies and techniques for addressing urban heat, such as using cool materials and green infrastructure. It was also measured using a five-point Likert scale ranging from 0 (none) to 4 (a great deal).

2.4. Data analysis

Initially, descriptive statistics were used to gain insights into the perceived severity of heat-induced physiological and psychological diseases, as well as the impact on daily functioning, knowledge, and awareness of heat impact reduction. To assess the normality of the dataset, normal distribution analyses, including the Kolmogorov-Smirnov and Shapiro-Wilk tests, were conducted. As the data did not meet normality assumptions, non-parametric tests were applied for subsequent analyses. The perceived severity of physiological and psychological disorders was determined using a nonparametric analysis, the Mann-Whitney U-test. The Kruskal-Wallis H-test was employed to examine differences in these disorders among various demographic groups. Pairwise-comparison analyses were conducted to identify the most susceptible groups. Logistic regression models, such as ordinal logistic regression for categorical dependent variables and binary logistic regression for dichotomous dependent variables, were utilized to identify influential factors that may explain the knowledge, perception, physiological and psychological consequences of urban heat. Statistical significance was determined at a p-value of less than 0.05. All analyses were conducted using R software (version 4.3.2).

3. Result

3.1 Demographic characteristics

Table 1 presents the demographic information of the respondents. Most respondents were male (57.9%) and aged between 18 and 30 (88%) years old, with an average family size of 4.79(±1.67). Over half of the respondents were students (60.4%) and had an undergraduate education (53.1%). Approximately 33% of participants had a monthly income between 2000 and 4000 BDT, with 29.8% having an income greater than 40000 BDT. Most (41.2%) lived in apartments and relied on fans for cooling (81.3%). Only 2.2% of respondents used natural ventilation. Around 43% reported having greenspaces within a 5-minute walk, while 36% had a 5-to-30-minute walking distance. Approximately 29% spent 3-5 hours outside during hot summer days, with 27.7% spending more than 5 hours. Most respondents rated their health as good (46.1%) or fair (41.4%).

Table 1. Demographic characteristics of the respondents (n = 898).

Variables	Descriptions	n (%)
Gender (GEN)	Male	520 (57.9)
	Female	378 (42.1)
Age (years) (AGE)	18−30	797 (88.0)
	>30	101 (11.2)
Education (EDU)	≤College	180 (20.0)
	Undergraduate	477 (53.1)
	≥Postgraduate	241 (26.8)
Family size (FS)		4.79 (±1.67)
Occupation (OCCU)	Unemployed	80 (8.9)
	Student	542 (60.4)
	Employed	276 (30.7)
Monthly family income (BDT) (INC)	0-10000	160 (17.8)
	10001-20000	173 (19.3)

	20001-40000	297 (33.1)
	>40000	268 (29.8)
Housing pattern (HP)	Apartment	370 (41.2)
	Pacca	285 (31.7)
	Semi-pacca	182 (20.3)
	Katcha	61 (6.8)
Cooling condition at home (CCH)	Fan	730 (81.3)
	Air condition	18 (2.0)
	Fan & Air condition	130 (14.5)
	Natural ventilation	20 (2.2)
Green space distance (GSD)	Within 5 min walk	394 (43.9)
	5-30 min walk	329 (36.6)
	>30 min walk	175 (19.5)
Time spent in outdoor (hours) (TSO)	<1	138 (15.4)
	1-3	247 (27.5)
	3-5	264 (29.4)
	>5	249 (27.7)
Self-rated health (SRH)	Poor	20 (2.2)
	Fair	372 (41.4)
	Good	414 (46.1)
	Very good	73 (8.1)
	Excellent	19 (2.1)

BDT, Bangladeshi Taka (Currency)

3.2. Perceived heat stress feel, perceived severity of physiological and psychological impacts

Figure S1 summarizes the perceived intensity of urban heat stress and its physiological and psychological impact. A substantial portion of urban residents (38.53% "often" and 24.83% "very often") experienced heat stress regularly, while others reported experienced it "sometimes" (27.73%), and a minority reported "not at all" (4.12%) or "rarely" (4.79%). For physiological effects, 43.10% reported moderate impacts, and 14.70% to 28.51% experienced severe to extra severe impacts, with only 0.67% reported no impact. Regarding psychological impacts, 40.73% experienced moderate impacts, 27.06% reported severe impacts, and 11.25% reported extra severe impacts, while 2% reported no psychological impact from urban heat stress.

Figure 2 & Table S1 illustrates the variability in heat stress perception and its physiological and psychological effects. Female respondents exhibited 1.47 times more severe heat stress than males (OR, 95%CI=1.47, 1.19−1.97). Respondents lived in pacca houses experienced less heat stress than apartment dwellers (OR, 95%CI=0.72, 0.53−0.96). Additionally, spending over 5 hours outdoors daily lead to 1.44 times more heat stress compared to spending less than 1 hour outside (OR, 95%CI=1.44, 0.99−2.23).

Figure 2 & Table S1 illustrates the variation in the severity of physiological impacts. Females perceived physiological impacts as 1.62 times more severe than males (OR, 95% CI = 1.62, 1.25−1.10). Respondents with both fan and air conditioning at home perceived a 1.63 times higher physiological impact than those with only a fan (OR = 1.63, 1.16−2.39, $p < 0.05$). Respondents with better health conditions corresponded to less severe physiological impact (**Figure 2 & Table S1).**

Like physiological impacts, psychological impacts also varied, with females reporting 1.33 times more impact than males (OR = 1.33, 1.01−1.66, $p < 0.05$). Additionally, respondents with only air conditioning or both fan and air conditioning reported severe psychological disturbance **(Figure 2 & Table S1).**

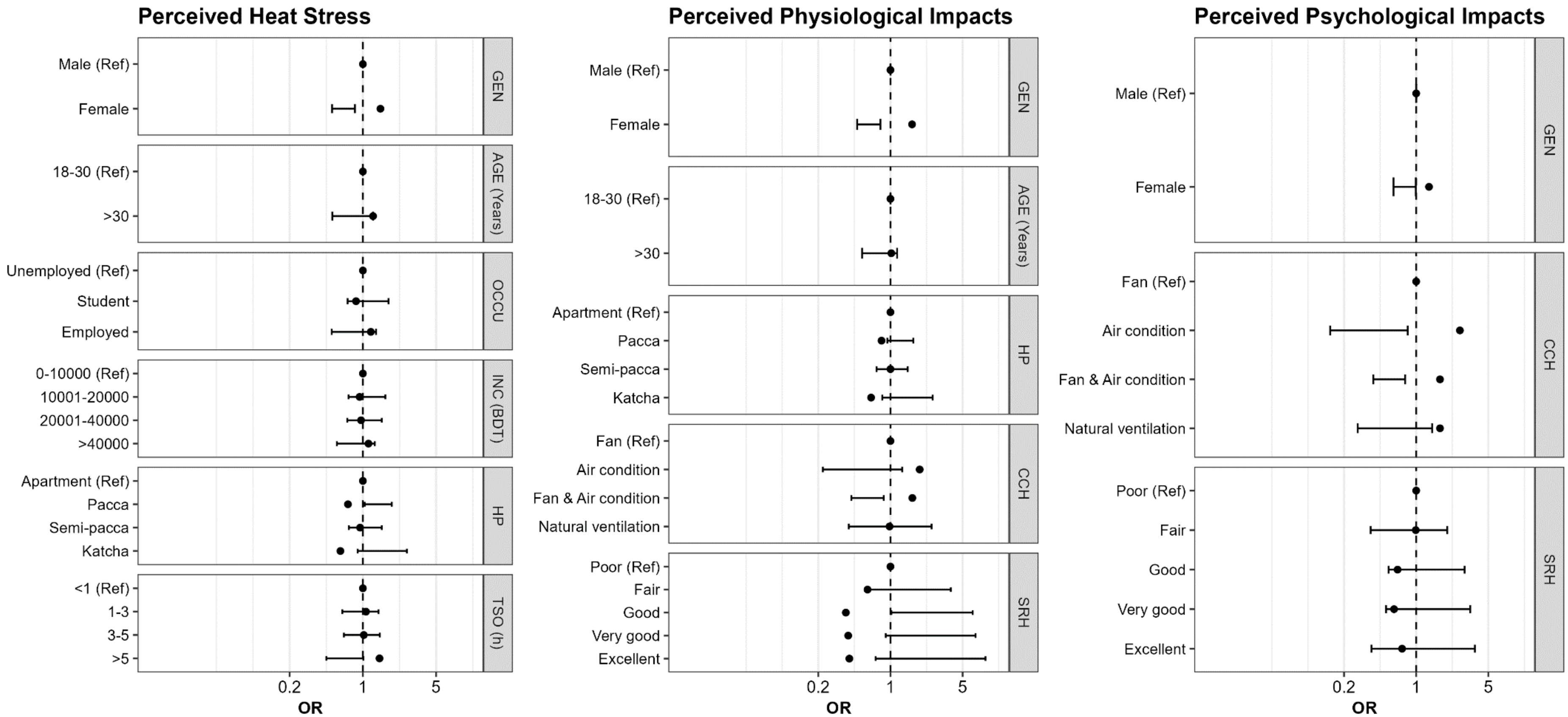


Figure 2. Sociodemographic variables influencing the perceived heat stress feel, perceived severity of physiological and psychological impacts (ordinal logistic regression) (n =898) (GEN, Gender; AGE (Years), Age (Years); OCCU, Occupation; INC (BDT), Monthly Family Income (BDT); HP, Housing pattern; TSO (h), Time spent in outdoor (hours); CCH, Cooling condition at home; SRH, Self-rated health).

3.3. Symptoms of heat-related physiological and psychological illness

Figure S2 summarizes the heat-related physiological and psychological disease symptoms. Skin heat damage was the most common physiological symptom (46.40%), followed by digestive system disease (29.10%), respiratory disease (27.30%), and eye illness (16.10%). Cardiovascular disease, metabolic disease, and urinary system illness each accounted for less than 10%. The most frequent psychological impacts included difficulty in controlling temper (73.60%) and emotional irritability (73.60%). Other effects, such as little interest in things (63.80%), low mood (61.90%), poor appetite (45.40%), and trouble concentrating (44.80%), were also reported at similar percentages, followed by a decline in memory (28.20%) and insomnia (15.60%).

3.4. Variability of physiological and psychological impacts

Figure 3 & Table S2 illustrate variations in physiological symptoms among demographic characteristics. Females were more likely to experience respiratory disease (OR, 95%CI=5.48, 1.17-39.15) and skin heat damage (OR, 95%CI=1.76, 1.32-2.35) than males. Respondents over 30 years old were more vulnerable to metabolic disease symptoms (OR, 95%CI=3.04, 1.06-8.53) than younger respondents. Employed individuals were 2.45 times more likely (95%CI=1.31-4.81) to develop digestive system disease symptoms. Those with a fan and air conditioning were 1.59 times more susceptible (95%CI=1.03-2.43) to skin heat damage symptoms. Conversely, respondents in very good health were less susceptible to eye illness symptoms (OR, 95%CI=0.23, 0.06-0.79).

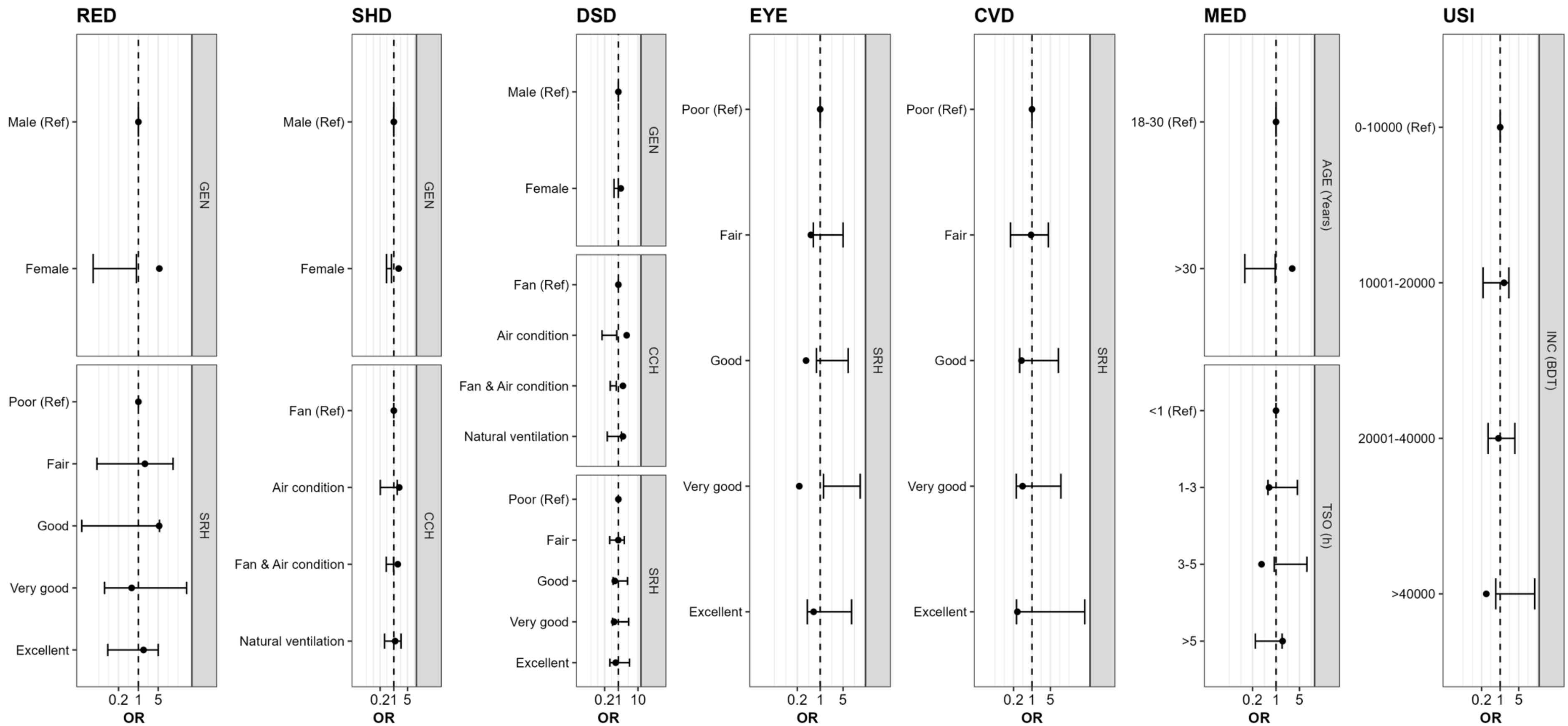
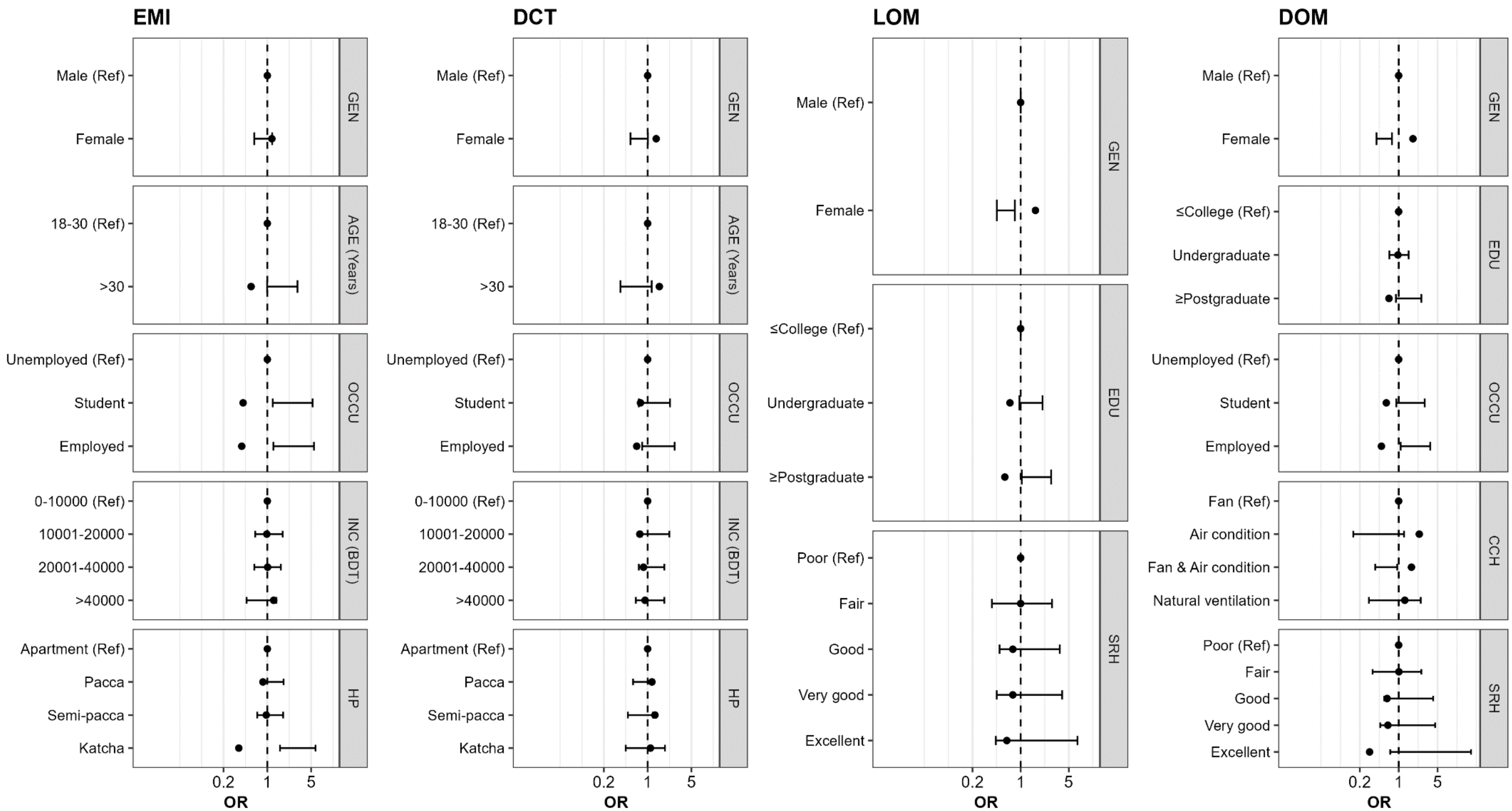


Figure 3. Sociodemographic variables influencing the symptoms of physiological illness (logistic regression) (n =898) (RED, Respiratory Disease; SHD, Skin Heat Damage; DSD, Digestive System Disease; EYE, Eye Illness; CVD, Cardiovascular Disease; MED, Metabolic Disease; USI, Urinary System Illness; GEN, Gender; AGE (Years), Age (Years); INC (BDT), Monthly Family Income (BDT); TSO (h), Time spent in outdoor (hours); CCH, Cooling condition at home; SRH, Self-rated health).

The variability of the symptoms of psychological illness with demographic characteristics are illustrated in **Figure 4 & Table S3**. Female respondents were 1.64 (95%CI=1.21-2.21), 1.81 (95%CI=1.32-2.50), 1.53 (95%CI=1.04-2.29), and 2.01 (95%CI=1.50-2.69)-times more likely to develop low mood, decline of memory, insomnia and poor appetite symptoms, respectively, than their counterparts. Further, higher-income respondents were highly susceptible to insomnia (OR, 95%CI=2.43, 1.27-4.75) and little interest in things symptoms (OR, 95%CI=1.95, 1.19-3.20). Respondents having both fan and air condition were highly susceptible to a decline of memory (OR, 95%CI=1.70, 1.06-2.64) and poor appetite (OR, 95%CI=1.66, 1.08-2.56). Similarly, respondents who spent more than 5 hours outdoor during hot weather were high susceptible to poor appetite (OR, 95%CI=0.72, 1.08-2.74).

In contrast, the respondents with over 30 years old were less likely to develop little interest in things (OR, 95%CI=0.57, 0.35-0.96) and poor appetite (OR, 95%CI=0.59, 0.35-0.99). Similarly, respondents with higher levels of education were less susceptible to low mood symptoms (OR, 95%CI = 0.59, 0.36-0.96). In terms of occupation, both students (OR, 95%CI=0.41, 0.19-0.82) and employed (OR, 95%CI=0.39, 0.18-0.80) were less susceptible to emotional irritability, respectively. Employed individuals were also less susceptible to a decline of memory symptoms (OR, 95%CI=0.49, 0.27-0.92). Respondents who lived in katcha house were less susceptible to emotional irritability (OR, 95%CI=0.35, 0.17-0.63). Further, respondents with good to excellent health conditions were less susceptible to insomnia and poor appetite.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DCT
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20001-40000
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INC (BDT)
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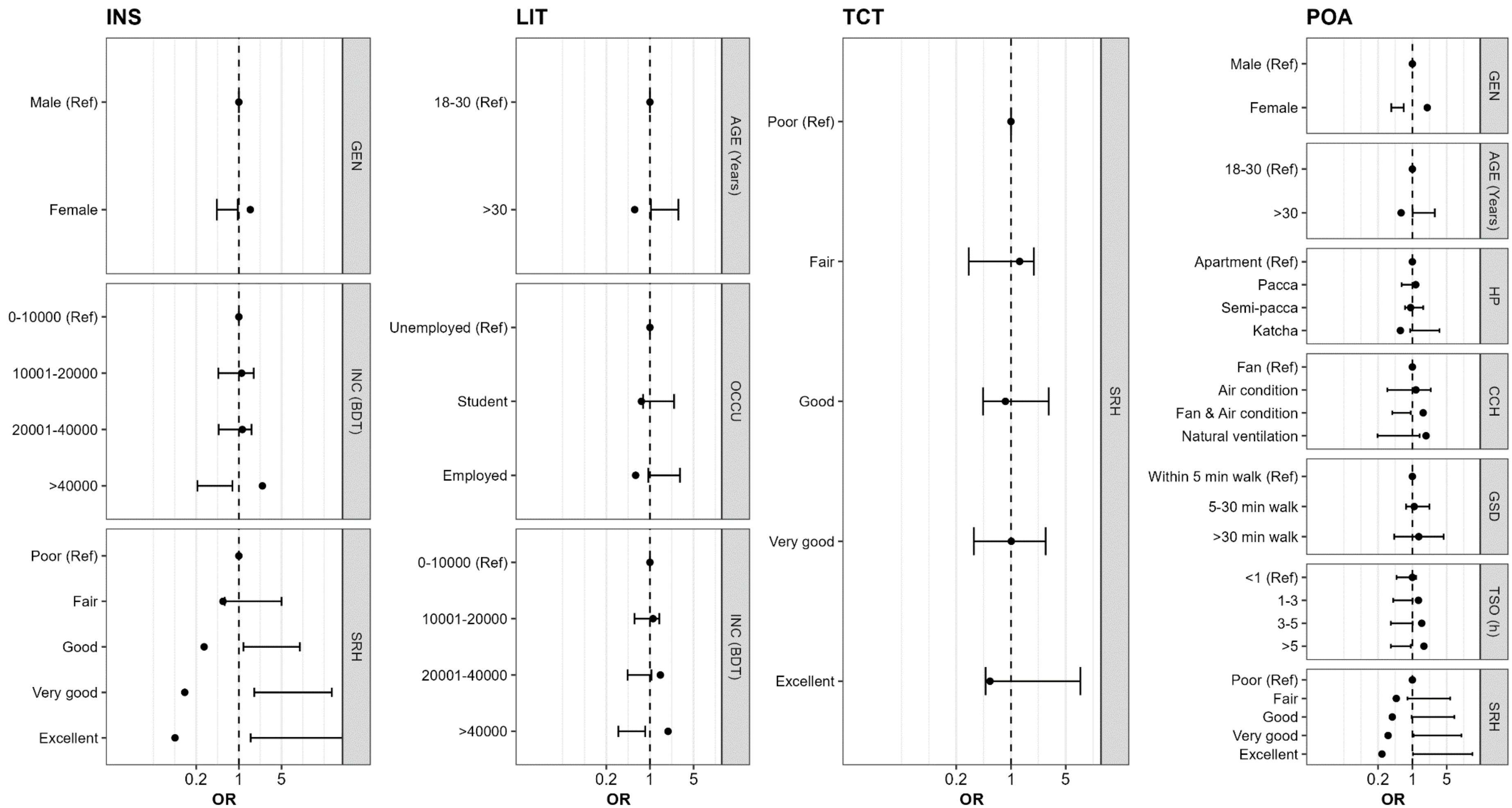

Figure 4. Sociodemographic variables influencing the symptoms of physiological illness (logistic regression) (n =898) (EMI, Emotional Irritability; DCT, Difficulty to Control Temper; LOM, Low Mood; DOM, Decline of Memory; INS, Insomnia; TCT, Trouble on Concentration Things; LIT, Little Interest on Things; POA, Poor Appetite; GEN, Gender; AGE (Years), Age (Years); OCCU, Occupation; INC (BDT), Monthly Family Income (BDT); HP, Housing pattern; CCH, Cooling condition at home; GSD, Green space distance; TSO (h), Time spent in outdoor (hours); SRH, Self-rated health).

3.5. Urban heat impacts and its distribution on daily life functioning

Figure S3 illustrates the impact of heat on respondents' daily functions, including outdoor activities, work/study, transportation, sleep/rest, and diet. Around 46.5% of respondents reported moderate heat effects on outdoor activities, with 25.2% experiencing severe impact and 12.2% having extra severe impact. Similar patterns were observed for other aspects of daily functioning, with moderate impacts being the most common, followed by severe and extra-severe impacts. Notably, approximately 5-6% stated no heat impact on their activities, while 10-15% reported only minimal effects **(Figure S3).** Comparing the effects on various activities, transportation, sleep/rest, work/study, and diet were most affected, with transportation having the highest impact (2.49) and diet significantly affected in all cases (1.95). However, heat's effects on outdoor activities were less and insignificant **(Figure S4).**

The variability of urban heat impacts on daily life functioning with demographic characteristics are presented in **Figure 5 & Table S4**. Respondents who lived in katcha house were less affected by the urban heat during work or study (OR, 95%CI=0.49, 0.27-0.88), transportation (OR, 95%CI=0.49, 0.28-0.86), sleep or rest (OR, 95%CI=0.39, 0.22-0.69) and diet (OR, 95%CI=0.43, 0.24-0.76). Further, respondents with over30 years old were less affected by urban heat while using any transportation (OR, 95%CI=0.56, 0.35-0.87). In contrast, respondents with higher incomes were affected by the urban heat during transportation use. However, no demographic factors significantly impacted the outdoor activities by urban heat.

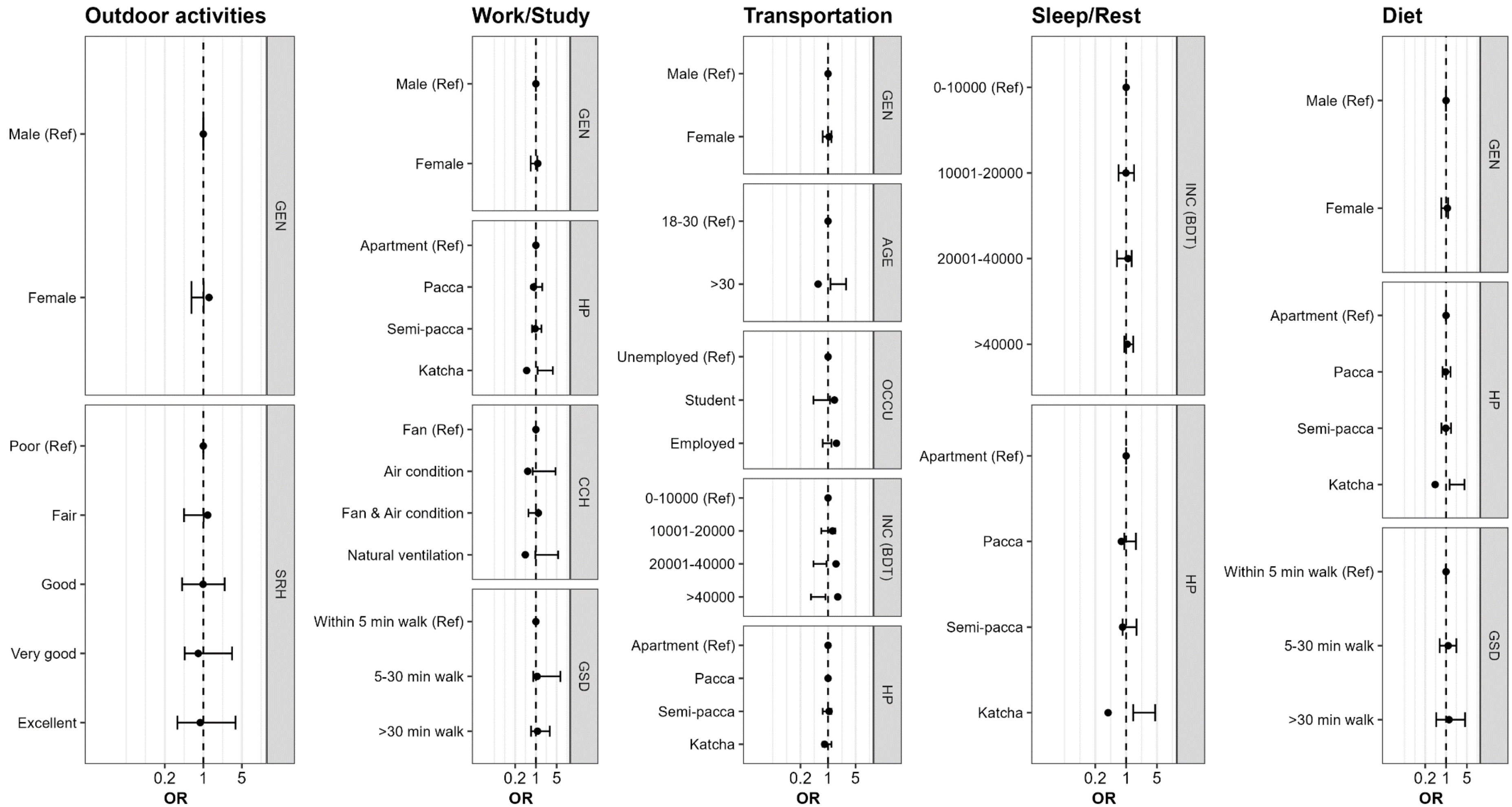

Figure 5. Examination of influence of sociodemographic variables on the daily life functioning due to urban heat (n = 898).

3.6. Knowledge and importance urban heat impact reduction

Figure S5 presents respondents' awareness and knowledge of various strategies to reduce the heat impact. About 42% had moderate knowledge, with only 8% having substantial knowledge. Regarding awareness, 51% considered it extremely important, 35% saw it as highly important and only 1% found it unimportant **(Figure S5).** When comparing perceived heat stress, the importance of heat impact reduction, and knowledge of heat impact reduction, awareness of heat impact reduction (3.34) was found to be more prevalent than knowledge (1.90) and significantly influenced by respondents' urban heat stress **(Figure S6).**

Figure 6 & Table S5 show the variability examination of awareness and knowledge for heat impact reduction with sociodemographic characteristics. The individuals with undergraduate (OR, 95%CI=1.67, 1.16-2.39) or post-graduate (OR, 95%CI=2.73, 1.73-4.33) education were significantly more likely to have a higher level of knowledge about heat impact reduction. In contrast, individuals over 30 years old (OR, 95%CI=0.41, 0.54-0.95) who live in Katcha houses (OR, 95%CI=0.61, 0.33-0.94) were significantly less likely to have a low level of knowledge about heat impact reduction. However, none of demographic variables predicted the individual's awareness for heat impact reduction.

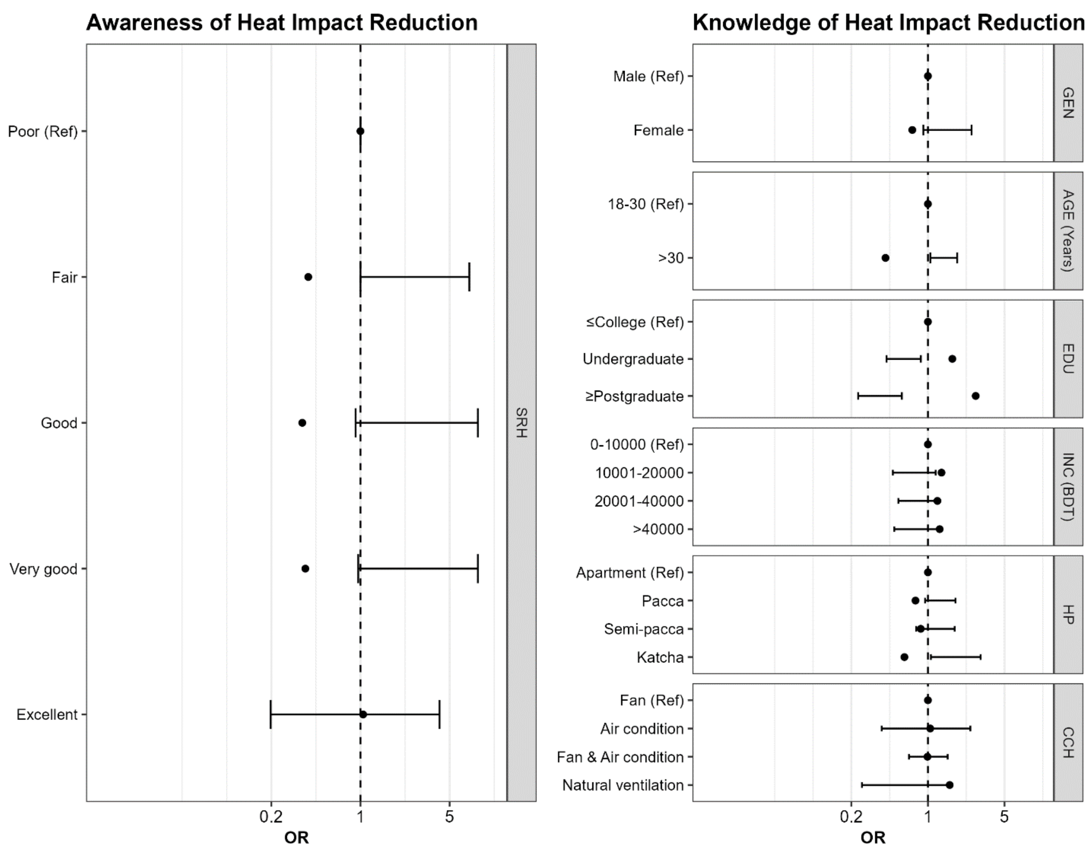

Figure 6. Examination of influence of sociodemographic variables on the awareness and knowledge for heat impact reduction (n = 898).

4. Discussion

4.1. Comparison of perceived heat stress feel, heat impacts, knowledge and awareness

Our study reveals that a significant proportion of individuals in major Bangladeshi cities regularly experienced urban heat stress, with most indicating it occurs "often" or "very often." Although awareness of the heat's impacts was moderate (scoring 3.34), the knowledge level (1.90) lagged significantly behind the perceived heat stress. This aligned with a prior study, which found that many experienced severe heat stress while having limited knowledge of heat mitigation measures (He *et al.*, 2022). In our findings, urban residents in these areas reported substantial impacts on their physiological and psychological well-being, with a more significant effect on physical health (2.44) than mental well-being (2.27). This underscores the need for effective heat reduction strategies to address potential health issues, including skin damage, digestive problems, dehydration, and heat-related illnesses, in line with previous studies emphasizing the impact of urban heat stress on both physiological and psychological well-being (Ebi *et al.*, 2021; Liu *et al.*, 2021).

Our findings align with prior studies, confirming that Skin Heat Damage (SHD) is the most prevalent physiological symptom among respondents (He *et al.*, 2022; Yuan *et al.*, 2022). SHD, attributed to prolonged exposure to high temperatures, produces red, irritated, and painful skin. Heat stress can disrupt the skin's natural cooling mechanism, causing sweating, leading to dehydration and exacerbating SHD symptoms (Williams, 2021). Prior studies suggest the effectiveness of interventions like sunscreen use, seeking shade, and specialized clothing to mitigate SHD risk. However, it's important to recognize that these strategies may not universally apply or be practical in certain settings, such as outdoor workplaces (Linos *et al.*, 2011). Consistent with earlier studies, our results also highlight the common co-occurrence of other symptoms, including Digestive System Disease (DSD), Respiratory Disease (RED), and Eye Illness (EYI) due to heat stress (Anderson *et al.*, 2013; Yuan *et al.*, 2022). The underlying mechanisms may involve the inflammatory and oxidative stress effects of high temperatures, potentially damaging cells and tissues in the digestive, respiratory, and ocular systems (Pizzino *et al.*, 2017). It's worth noting that symptoms related to CVD, MED, and USI were less frequently reported by study participants, with fewer than 10% of respondents indicating these concerns.

Our results underscore the significant psychological impact of heat stress on individuals, with challenges in emotion regulation and emotional irritability emerging as the most commonly reported effects. These psychological consequences can result in heightened stress, reduced concentration, and difficulties in maintaining focus, elevating the risk of accidents and unfavorable outcomes (Kontogiannis, 2006), in line with prior research (He *et al.*, 2022; Yuan *et al.*, 2022). Furthermore, a substantial proportion of respondents reported decreased mood, poor appetite, and reduced attention to tasks warrant attention. Earlier studies have also revealed a connection between heat stress and adverse mental health effects, emphasizing the importance of addressing these psychological consequences (Hansen *et al.*, 2008; Nitschke *et al.*, 2011).

Our study reveals a moderate impact of urban heat on daily activities, aligning with findings from a previous study (He *et al.*, 2022). Activities like transportation, often conducted outdoors or in non-air-conditioned spaces, are more susceptible to heat-related disruptions. Factors such as limited access to water and inadequate nutrition can exacerbate this impact. A study from Thailand similarly highlighted the heat stress affecting work productivity, sleep, transportation, household tasks, and physical activity (Tawatsupa *et al.*, 2012). Notably, a minority of respondents reported minimal or no impact on their daily activities, possibly due to heat adaptation or access to cooling measures. While outdoor activities were less affected, this indicates people's adaptive behavior in limiting such activities during hot weather, necessitating interventions promoting safe outdoor engagement.

4.2. Variability of heat-induced impacts with demographic characteristic

Our findings suggest that there is significant variability in the perceived urban heat severity and impacts among different groups, such as gender, age, education, occupation, housing pattern, cooling condition at home, time spent outdoors, and perceived health condition.

Gender emerged as a pivotal factor influencing susceptibility to heat-related effects and illnesses, with females more vulnerable to heat stress in terms of both physiological and psychological heat-related impacts. The heightened vulnerability of women might be attributed to various physiological distinctions, such as a higher body fat percentage and lower sweat gland density, increasing the risk of heat-related illnesses (Kenney, 1985; Notley *et al.*, 2017). Furthermore, women's lower aerobic capacity and blood volume make them more heat-sensitive, posing challenges in dissipating heat and maintaining core body temperature (Kazman *et al.*, 2015). Societal and cultural norms can compound this vulnerability, as women often shoulder additional domestic responsibilities involving cooking and cleaning, exposing them to elevated indoor temperatures (Okello, Devereux and Semple, 2018). This aligns with findings from previous research in China, confirming psychological vulnerability among females (Yuan *et al.*, 2022).

Age significantly influences the susceptibility to heat-related physiological illnesses, particularly metabolic disorders. As individuals age, they may exhibit heightened sensitivity due to reduced thermoregulatory capacity, resulting in diminished sweating, skin blood flow, and cardiovascular function. These age-related changes impair the body's ability to regulate temperature, compounded by decreased physical fitness and increased body adiposity, elevating the risk of heat-related illness (Kenny *et al.*, 2010). Notably, our findings indicate that comparatively older individuals exhibited lower sensitivity to specific psychological impacts of heat stress, such as emotional irritability, temper control difficulties, reduced interest in activities, and poor appetite. They were also less affected in transportation use by heat and possessed lower knowledge of heat impact reduction. This may stem from older individuals' accumulated experience living in hot climates, enabling them to develop effective coping mechanisms or a deeper understanding of heat stress causes and effects (Malmquist *et al.*, 2022; Mukhopadhyay and Weitz, 2022). However, it's crucial to recognize that these trends may not apply universally to all older individuals, necessitating further research for a comprehensive understanding of the age-heat stress relationship.

Education was not a sensitive factor to the severity of high heat stress. Highly educated individuals were less likely to report psychological impacts like low mood due to urban heat stress, aligning with previous research (He *et al.*, 2022). Higher education may provide better access to coping resources and the knowledge and skills to implement heat mitigation strategies, such as seeking air-conditioned spaces or staying hydrated. This corresponds to the trend of increasing highly educated individuals who often work in air-conditioned offices and have better access to resources (He *et al.*, 2022). Additionally, our study reveals that higher education was associated with greater knowledge of urban heat stress, likely resulting from developing critical thinking skills through formal education. This underscores education's crucial role in promoting awareness and understanding of urban heat stress and its effects.

Employment emerged as a significant factor in developing heat-related physiological symptoms, such as digestive disorders (DSD). This could be attributed to increased workplace heat exposure, particularly for those working outdoors or in non-air-conditioned environments. Work-related stress may exacerbate DSD, given the known association between stress and digestive problems (Huerta-Franco, 2013). Additionally, sedentary behavior and extended office hours may contribute to DSD, with employed individuals potentially more affected due to their work schedules (Daneshmandi *et al.*, 2017). Interestingly, both students and employed individuals in our study exhibited lower sensitivity to heat-induced psychological impacts. This may be attributed to their access to resources and information aiding heat stress coping. Students benefit from air-conditioned classrooms and libraries, while employed individuals often have air-conditioned workplaces. The prevalence of highly educated individuals in our study sample suggests that their heightened awareness of heat-related risks and mitigation strategies may also mitigate psychological heat stress impacts.

Consistent with earlier studies (Harlan *et al.*, 2006), our study found that housing type, such as living in a pacca house, exhibited greater susceptibility to heat stress severity and psychological ailments, particularly insomnia. Individuals living in urban areas with less green space and poorly ventilated or insulated homes are at higher risk for heat stress due to the Urban Heat Island effect and reduced access to cooling (Vandentorren *et al.*, 2006). The heat-retaining properties of materials like brick and cement, along with inadequate ventilation and cooling, contribute to elevated indoor temperatures and less comfort, leading to difficulty sleeping and other psychological effects. Conversely, those living in a Katcha house experienced fewer psychological impacts and disruptions to their daily lives due to heat, albeit with less knowledge about heat impact reduction. Katcha houses typically offer natural ventilation and improved thermal efficiency, affording better heat stress protection. Residents may rely on adaptive strategies stemming from their lifestyle, reducing psychological impacts. However, limited access to information and resources may explain their lesser knowledge about heat impact reduction. Research has shown that individuals in traditional or rural housing types exhibit greater heat adaptation strategies while potentially having limited access to relevant resources (Garg *et al.*, 2016; Ravindra *et al.*, 2019).

An artificial cooling system was a critical factor in high heat stress. The houses equipped with both fans and air conditioning systems were associated with elevated heat stress and heat-related psychological issues, like memory decline and reduced appetite. This may result from the reduced effectiveness of artificial cooling compared to natural ventilation in alleviating heat stress, as artificial systems can increase indoor air pollution and mold growth (Grosskopf, Oppenheim and Brennan, 2008), linked to chronic heart and lung diseases (Richard, Kosatsky and Renouf, 2011). While prior evidence doesn't directly link artificial cooling to memory decline or poor appetite, prolonged indoor time in humid, poor air quality may contribute to these mental health issues (Fang, Luo and Lu, 2023). Conversely, houses with only natural ventilation experienced fewer heat-related issues during transportation. Residents with natural ventilation might spend more time outdoors, benefiting from natural breezes and lower humidity. These households may also prefer sustainable transportation methods, like walking or biking, which offer a natural cooling effect.

Extended outdoor exposure to hot weather was a critical factor in high heat stress and heat-related psychological illnesses such as poor appetite. This outcome can be attributed to the higher temperatures and direct sunlight encountered outdoors, leading to increased body temperature and dehydration. Prolonged outdoor exposure to the heat also elevates stress levels and fatigue, further compounding heat-related psychological symptoms, including poor appetite. Prior research supports these findings by illustrating how extended exposure to high temperatures can disrupt appetite and metabolism (Kojima *et al.*, 2015; Zakrzewski-Fruer *et al.*, 2021).

Healthy respondents were less vulnerable to heat stress impact compared to those who were less healthy. Such findings are consistent with previous studies, indicating that healthy respondents were 70% more likely than unhealthy respondents to report lower levels of heat stress (Zander *et al.*, 2018). Individuals with better health likely have better thermoregulatory and cardiovascular function, which can help them to better cope with heat stress. Further, healthy individuals were more likely to engage in physical exertion during the day may also help to tolerate higher levels of heat (Cui and Sinoway, 2014). However, more research is needed to understand further the mechanisms underlying these associations.

4.3. Health implications of urban heat island

Our study uncovers critical insights directly relevant to South Asian countries, offering actionable strategies to combat the adverse effects of urban heat. **Firstly,** many respondents regularly experienced heat stress, yet there was a significant gap in awareness and knowledge concerning heat impact reduction. To address this, we urgently need measures to mitigate urban heat's impact and enhance public awareness. Educating individuals and communities about the risks associated with urban heat and strategies for mitigation is essential (Leal Filho *et al.*, 2018). Implementing city-specific urban heat alert and warning systems, such as informative signs in buildings and outdoor spaces, can play a pivotal role. These systems inform people about the current heat severity and its potential health risks, thus bolstering awareness and motivating individuals to take proactive steps to protect themselves from heat exposure. Moreover, these interventions must be tailored to each city's unique context, considering the local dynamics of objective and subjective urban heat severity, perceived physiological and psychological risks, and demographic characteristics (Keramitsoglou *et al.*, 2017).

Second, our study reveals a higher vulnerability to the physiological effects of urban heat compared to psychological impacts. A comprehensive approach is necessary in heat-health plans, emphasizing the importance of addressing both. Prioritizing the mitigation of heat-induced physical issues, like skin heat damage, eye diseases, and chronic digestive ailments, is crucial to prevent long-term health problems. This entails providing medical care and promoting heat-reducing behaviors (Groot, Abelsohn and Moore, 2014). Additionally, emergency measures should include psychological well-being support during extreme heat periods offering access to mental health services for those experiencing heat-related distress (Palinkas *et al.*, 2020).

Third, demographic factors play a pivotal role in addressing heat-related illness. Particularly, females, individuals above 30 years old, and employed workers exhibit heightened vulnerability to both the physiological and psychological impacts of urban heat. Prioritizing interventions for these groups is imperative, encompassing targeted education and awareness campaigns, as well as tailored resources and support. It is equally vital to consider the unique needs and experiences of these demographics when formulating and executing urban heat management strategies, including safe and accessible transportation options. At an individual level, adopting effective heat stress adaptation plans in workplaces, such as adjusting activity patterns, selecting suitable times and locations for activity, and utilizing cooling facilities, is crucial. Awareness of heat stress signs and symptoms and prompt action to prevent or address these conditions is essential (Nunfam *et al.*, 2018).

Fourth, prioritize mitigating heat-related health impacts by addressing living environments. Our study reveals that pacca houses increase vulnerability to heat stress. Encourage interventions like natural ventilation methods (e.g., cross-ventilation and shading) and sustainable cooling practices (such as evaporative and natural systems) for effective relief without excessive energy use (Elhassan, 2023). Additionally, public awareness campaigns and education programs can be developed to inform individuals about the potential negative health impacts of artificial cooling systems and the benefits of natural ventilation and sustainable cooling methods.

Fifth, it is crucial to integrate climate-resilient infrastructure strategies into regulations and urban development plans. This includes incorporating rooftop gardens, rewarding indoor green spaces, and using building materials that lower temperatures in the city (Sharma *et al.*, 2018). It is also important to address underlying issues, such as lack of access to adequate housing and cooling equipment and address the root causes of climate change through sustainable urban planning and reducing greenhouse gas emissions. Furthermore, interventions should be inclusive and address the needs of marginalized communities that may be more vulnerable to urban heat stress. Overall, a comprehensive and multi-faceted approach is needed to address urban heat stress in South Asian countries effectively.

4.4. Limitations of the study

This study has several limitations that should be acknowledged when interpreting the findings. Firstly, the study relied on self-reported data, which may be subject to bias, such as social desirability or recall bias. The study's findings may not be generalizable to other populations, as the study only focused on urban areas in a South Asian country. Furthermore, the study did not consider other factors that may influence the relationship between urban heat and health outcomes, such as air pollution (Rainham and Smoyer-Tomic, 2003). Finally, the study did not measure objective measures of heat exposure, such as temperature or humidity, which could have provided additional insights into the relationship between urban heat and health outcomes.

5. Conclusion

This study provides valuable insights into the impact of urban heat stress on the health and well-being of individuals living in urban areas of Bangladesh. The findings reveal that despite a significant portion of individuals experiencing heat stress regularly, awareness and knowledge of heat impact reduction was relatively low. Perceived physiological impacts were more severe than psychological impacts, and urban heat had moderate impacts on daily functioning, with transportation and sleep/rest being the most affected. Factors such as being female, older, employed, having an artificial cooling system at home, and spending more time outdoors were critical factors for heat severity and associated physiological and psychological impacts of heat. In contrast, being a student, more highly educated, living in a katcha house, and being healthy was associated with less sensitivity to various physiological and psychological impacts of heat. These findings highlight the need for targeted interventions to address urban heat stress in Bangladesh, particularly among vulnerable populations. Recommendations include promoting behaviors that can help individuals cope with heat stress and integrating climate-resilient infrastructure practices into urban development plans to reduce heat exposure.

Ethics approval and consent to participate

All participants provided electronic consent before taking the survey and were given the option to stop the survey at any time. The survey did not require the disclosure of personal information such as names or email addresses. The study was approved by the research ethical clearance committee of Khulna University, Bangladesh (KUECC-2022/09/32).

Consent for publication

All authors consent to publish this article in *Urban Climate*.

CRediT authorship contribution statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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