2019

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10.1007/s00484-019-01775-1

The nexus between social impacts and adaptation strategies of workers to occupational heat stress: A conceptual framework

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Abstract

Adverse effects of occupational heat stress in the context of changing climate on working populations are subtle but considerably harmful. However, social dimensions and impacts of climate change-related occupational heat concerns on workers' safety and health, productivity, and well-being are often overlooked or relegated as minor issues in social impact analyses of occupational heat exposure due to climate change. This paper offers a conceptual framework based on an appraisal and synthesis of the literature on social impacts of climate change-related occupational heat exposure on workers' safety and health, productivity, and social welfare and the quest to localise and achieve sustainable development goals. A sustained global, national, institutional, and individual collaborative involvement and financial support for research, improved adaptation and social protection strategies, predominantly in the developing world, where a large number of the people work outdoors, can reduce heat exposure and boost the resilience and adaptive capacity of workers to facilitate efforts to achieve sustainable development goals.

Keywords: adaptive capacity, global warming, work-related heat exposure, social health, sustainable development goals, working populations

1. Introduction

Diverse working populations of the world are experiencing adverse effects of occupational heat stress risks due to global climate change. Rising temperatures result in increased heat stress risk (Haines et al., 2007; McMichael et al., 2006). Heating of the climate system from rising concentrations of human-enhanced greenhouse gases (GHGs) exemplified in carbon dioxide and methane emissions have increased global mean temperature by ~0.76 °C since the 1850s (Intergovernmental Panel on Climate Change [IPCC], 2014). Based on climate change modelling using global climate change scenarios (Representative Concentration Pathways [RCPs]), average ambient temperatures of the world are estimated to increase within the range of 1.4 °C - 5.8 °C by the year 2100 (IPCC, 2014).

The projected increase in the incidence and severity of heat stress and exposure events is expected to impact outdoor workers' health and will lead to a reduction in their work capacity or affect social well-being. Australia's climate change projections showed an increase in days with unsafe heat exposure from one day in the 1990s to 15-26 days for each year by the 2070s (Maloney & Forbes, 2011). Global labour productivity loss analysis over the period (1975-2200) showed that during hot and humid periods work capacity reduced by 37 percent and 20 percent based on RCP8.5 and RCP4.5 respectively (Dunne et al., 2013). However, intensifying temperature could help improve winter productivity in some regions. For instance, climate change had a positive consequence on winter wheat, spring wheat and barley production in northern and Siberian parts of Russia, but had adversely affected grain production in the southern part of the country (Belyaeva & Bokusheva, 2018).

Notably, there are records of heat impact on reduced work capacity, labour productivity and economic loss, social lives, forced migration due to loss of livelihood, and loss of GDP in India, Australia, U.S. and Africa (Burke et al., 2015; Kjellstrom, 2016; Kjellstrom et al., 2009b; Sahu et al., 2013; Venugopal et al., 2016a). For instance, absenteeism and reduced work performance due to heat exposure resulted in financial losses of US$655 per person and a total economic burden of US$6.2 billion in Australia (Zander et al., 2015). Furthermore, a global examination of yearly average temperatures and national Gross Domestic Product (GDP) for various countries indicated that up to 23 percent of global GDP would be lost due to climate change by the year 2100 (Burke et al., 2015). Similarly, due to climate change impacts, Nigeria and Ghana lost 3.3 percent and 3.2 percent of GDP in 2010 and are expected to lose 6.4 percent and 6.5 percent of GDP in 2030 respectively (Kjellstrom, 2016). In addition, incidents of heat exhaustion, cognitive and psychological performance effects were recorded among South African mine workers and Australian and Thai farmers (Berry et al., 2010; Tawatsupa et al., 2010).

Increased heat exposure occasioned by climate change leads to more significant effects of occupational heat stress (e.g., mortality, morbidity, loss of productive capacity, and reduced network relationship) for workers (Kjellstrom et al., 2016a; Lundgren et al., 2013). Studies of heat exposure in hot areas of Africa, Asia, Latin America and Australia show that several billions of people including workers may be in danger of heat stress effects (Kjellstrom et al., 2016a). Similarly, there are recorded cases of heat stroke-related deaths at work among South African and Qatari mine workers (Gibson & Pattisson, 2014; Wyndham, 1994). Four hundred and twenty-three people, including 68 crop farmers, died from heat stroke from 1992-2006 in the United States (U.S.) (Centres for Disease Control & Prevention (CDCP), 2008). Furthermore, excessive heat exposure amongst U.S. military, Central American sugarcane workers, and migrant construction

workers in Qatar has led to clinical damage to organs, heart overload and kidney damage due to heat exhaustion and dehydration (e.g., Gibson & Pattisson, 2014; Tawatsupa et al., 2012; Wesseling et al., 2013).

However, beyond safety and health, not much attention is being paid to the hazards of heat stress experiences in a changing climate on the productivity and social health of workers (Kjellstrom et al., 2016a; Schulte & Chun, 2009). For this reason, aspects of the 2030 Sustainable Development Goals (SDGs) recognised the importance of improving the well-being of people, including workers. The SDGs set an agenda to work toward global development over a 15-year period (2015-2030) (Pogge & Sengupta, 2015; United Nations (UN), 2015). The international development blueprint focuses on ending poverty (SGD 1), guaranteeing healthy lives and promoting well-being (SDGs 3), ensuring decent jobs and economic growth (SDGs 8), and combating intensifying temperature and climate change impacts (SDGs 13) (Pogge & Sengupta, 2015; UN, 2015). Climate change-related occupational heat stress refers to heat stress that is either driven by climate change or is aggravated by climate change. It is also a condition in which the human body exhibits inadequate physiological capacity to tolerate excess heat generated within and/or outside the body (Kjellstrom et al., 2016b). The risk and effect of heat stress on workers emanates from environmental, individual and occupational related heat exposure risks factors (Haines & Patz, 2004; Maté et al., 2016; Parsons, 2014; Schulte & Chun, 2009).

The social (e.g., network of relationships) and human (e.g., knowledge, skills, and abilities) capital embodied in workers are significant in reducing climate change and work-related heat stress vulnerability, and enhancing adaptive capacity. However, the occupational safety and health, productive capacity and social lives of outdoor workers are at risk due to increased ambient temperatures and higher relative humidity associated with climate change. Previous empirical and

review studies attest to the effect of climate change and work-related heat exposure on the health, efficiency, social well-being, and adaptation strategies of people (Kjellstrom et al., 2016a; Schulte et al., 2016; Schulte & Chun, 2009; Venugopal et al., 2016a).

Much of the climate change and heat stress impact research focus on the health of the general population rather than occupational cohorts. However, the impacts of heat stress on workers' safety and health, efficiency, social well-being, and their adaptation strategies are not well described (Costello et al., 2009; McMichael et al., 2006). Furthermore, inadequate studies have used conceptual frameworks to illustrate how climate change and heat exposure influence workplaces and workers' productive capacity, social lives, and adaptation strategies in the context of the SDGs (Lucas et al., 2014; Schulte et al., 2016; Schulte & Chun, 2009). Not only do heat exposure effects due to changing climate relate to economic and environmental conditions, but they also impact negatively on social lives and health of people including workers (United Nations [UN], 2011; Nunfam et al., 2018).

Social impacts include the consequence of socioeconomic and natural events (e.g., projects, policies, heat exposure) which affect the corporeal and mental well-being of a person, socioeconomic groups, work environment and society. Social impacts often result in significant changes to at least the health and safety, environment, rights, participation in decision making, fears, culture, community, or political organisation of people (Mahmoudi et al., 2013; Vanclay et al., 2015). Heat stress social impact is exemplified in morbidity, injuries, reduced productive capacity, loss of employment, decreased income and disruption of social lives and comfort. Social impacts due to heat stress reflect those that directly affect the physical, social and emotional well-being of people including health effects, poverty and income inequality (Gasper et al., 2011; UN, 2011).

Workers' exposure to occupational heat stress ascribed to changing conditions of the climate viz-a-viz their social and human capital and the need to promote the SDGs is significant. Hence, the authors construct a framework to portray the conceptual pathways of climate change-related occupational heat stress, adaptation and the SDGs. The framework illustrates the conceptual dimensions and linkage between safety and health, productivity, and social well-being. It elucidates the repercussions of heat stress on SDGs based on the adequacy of workers' social protection, coping, and adaptation strategies. The paper advocates for the integration of social extents and impacts of physiological health, productivity, and social welfare ramifications of heat stress into climate change social impact assessments to enhance the SDGs. It also seeks to inform the ongoing discourse on climate change and social impact assessment as well as social protection and adaptation policies. Hence, this article reviews and synthesises salient literature on climate change, work-related heat stress, and workers' adaptation strategies. It proposes a conceptual framework depicting pathways of social extent and impacts of climate change-related occupational heat exposure and SDGs via the interconnected safety and health, productivity, and social well-being implications of work-related heat stress on workers.

2. Materials and methods

Fundamentally, the development of this conceptual framework was informed by a previous research study that reviewed and synthesised scholarly articles in peer-reviewed journals published within the period (2007 - 2017) to provide a current perspective of the literature (Nunfam et al., 2018). Accordingly, keywords including 'adaptation strategies', 'health and safety', 'social impact', 'social well-being', 'occupational heat stress', 'climate change', 'psychological behaviour', 'productivity', and 'workers' were used as part of the search strategy in a variety of

data repository (e.g., Google Scholar, ProQuest, PubMed, Science Direct, and Web of Science) and the references of selected relevant studies. The purpose was inter alia to identify evidence of journal articles with conceptual frameworks related to social impact of work-related heat stress and adaptation policies of workers in the context of climate change.

Overall, the procedure of database exploration culminated into 25 relevant studies out of 23,352 selected studies from which 123 findings were extracted (see Supplementary Tables 1 to 25) (Nunfam et al., 2018). The 25 relevant studies were selected based on an inclusion and exclusion criteria. To be included for review and synthesis, scholarly studies had to be peer-reviewed, published in the English language and related to occupational heat exposure risk and adaptation strategies. Similarly, the studies had to assess the effect of work-related heat stress on workers' productivity, health and safety, and social welfare and/or used conceptual frameworks to describe the linkages among climate change, occupational heat exposure, worker's safety and health, their social well-being, productivity, and adaptation strategies. However, we excluded from the review studies which: 1) were letters, editorials, reviews, comments and viewpoints; 2) assessed climate change-related precipitation, drought, increasing sea levels and rainstorms; 3) assessed the effect of heat stress on animals, crops, plants and ecosystems; and 4) were related to climate change mitigation. The included studies were presented according to author name(s), year of publication, title, study design, population and sample size, data collection methods and analysis, and author(s)' conclusions (Table 1). This paper relied on the extracted findings as secondary data for the purpose of data categorisation, which were synthesised into themes and illustrated with the aid of diagrams.

1 **Table 1: Summaries of findings in selected studies**

#	Author, year & title	Study design	Population & sample size	Methods	Data analysis	Author(s)' conclusions
1	Balakrishnan et al. (2010). Case studies on heat stress related perceptions in different industrial sectors in southern India	Case study	242 manufacturing workers	Questionnaires and Wet Bulb Globe Temperature (WBGT) index	Correlation analysis	Given the potential implications of future climate change-related increases in ambient heat stress that are likely to translate into workplace exposures in developing country settings
2	Crowe et al. (2013). Heat exposure in Sugarcane harvesters in Costa Rica	Descriptive study design	105 harvesters	WBGT and non-participatory observation	Descriptive analysis using WBGT data, metabolic rate and Threshold limit values	Sugarcane harvesters are at risk of heat stress for the majority of the work shift. Immediate action is warranted to reduce such exposures
3	Flocks et al. (2013). Female Farmworkers' Perceptions of Heat-Related Illness and Pregnancy Health	CBR approach using narrative interviews	35 female farmworkers	Focus group discussion	Thematic analysis	Participants believe that heat exposure can adversely affect general, pregnancy, and fetal health, yet feel they lack control over workplace conditions and that they lack training about these specific risks
4	Crowe et al. (2010). Heat exposure in sugarcane workers in Costa Rica during the non-harvest season	Exploratory observational study	45 sugarcane workers	WBGT	Descriptive analysis	It is therefore important to take action to decrease current and future heat-related risks for sugarcane 55workers in both harvest and non-harvest conditions and in all sugarcane growing regions in Costa Rica. It is also necessary to improve guidelines and occupational health standards for protecting worker health and productivity in the tropics
5	Stoecklin-Marios et al. (2013). Heat-related illness knowledge and practices among California hired farm workers in The MICASA study	Comparative study design	467 hired farm workers	structured interviews questions	Statistical analysis using multivariate survey logistic regression	The study suggests important areas to target for heat illness prevention in farmworker population, and that gender-specific approaches may be needed for effective heat illness
6	Tawatsupa et al. (2013). Association between heat stress and occupational injury among Thai worker: Findings of the Thai cohort studies	Cohort studies	58495 workers	Mail out health questionnaires	Logistic regression using STATA version 12	The study provides useful evidence linking heat stress to occupational injury in tropical Thailand and identifies factors that increase heat exposure

7	Tawatsupa et al. (2012). Association between occupational heat stress and kidney disease among 37816 workers in the Thai cohort studies (TCS)	Cohort studies	37816 workers	Self-reported questionnaires	Logistic regression	There is an association between self- reported occupational heat stress and the self-reported doctor diagnosed kidney disease in Thailand. There is a need for occupational health interventions for heat stress among workers in tropical climates
8	Sett and Sahu (2014). Effects of occupational heat exposure on female brick workers in West Bengal, India	Evaluative study design	120 brick moulders and carriers	WBGT and questionnaires	Statistical analysis using t-test and ANOVA	High heat exposure in brickfields during summer caused physiological strain in both categories of female brickfield workers
9	Luo et al. (2013).Exposure to ambient heat and urolithiasis among outdoor workers in Guangzhou, China	Correlational Case-control study design	190 cases and 760 control shipbuilding workers	2003–2010 health check data	Conditional logistic regression	Significant association between exposure to ambient heat and urolithiasis among outdoor working populations
10	Langkulsen et al. (2010). Health impact of climate change on occupational health and productivity in Thailand	Descriptive cross-sectional study	21 workers	WBGT and questionnaires	Descriptive and trend analysis	Climate conditions in Thailand potentially affect both the health and productivity in occupational settings
11	Sahu et al. (2013). Heat exposure, cardiovascular stress and work productivity in rice harvesters in India: Implications for a climate change future	Comparative study design	124 rice harvesters	WBGT and an interviewer-administered questionnaire	Trend and Statistical analysis using a t-test	High heat exposure in agriculture caused heat strain and reduced work productivity. This reduction will be exacerbated by climate change and may undermine the local economy
12	Krishnamurthy et al. (2017). Occupational Heat Stress Impacts on Health and Productivity in a Steel Industry in Southern India	Cross-sectional study design	84 steel worker	WBGT and structured questionnaires	Statistical analysis	High heat exposures and heavy workload adversely affect the workers' health and reduce their work capacities. Health and productivity risks in developing tropical country work settings can be aggravated by temperature rise due to climate change, without appropriate interventions
13	Tawatsupa et al. (2010). The association between overall health, psychological distress, and occupational heat stress among a large national cohort of 40,913 Thai workers	Cohort studies	40913 workers	Self-reported questionnaires	Descriptive statistical analysis	This association between occupational heat stress and worse health needs more public health attention and further development of occupational health interventions as climate change increases Thailand's temperatures
14	Delgado-Cortez (2009). Heat stress assessment among workers in a Nicaraguan sugarcane farm		22 sugarcane workers	data loggers and data collection sheet	Descriptive statistics and Chi-square analysis	Productivity improved with the new rehydration measures. Awareness among workers concerning heat stress prevention was increased

15	Venugopal et al. (2016b). Occupational heat stress profiles in selected workplaces in India	Experimental study design	442 workers	WBGT and questionnaires	Statistical analysis using Z-test a chi-square for bivariate	Reducing workplace heat stress benefits industries and workers via improving worker health and productivity. Adaptation and mitigation measures to tackle heat stress are imperative to protect the present and future workforce as climate change progresses
16	Dutta et al. (2015). Perceived heat stress and health effects on construction workers	A cross-sectional survey using mixed method approach	219 construction workers	WBGT, focus group discussion and survey questionnaires	Thematic analysis using grounded theory approach for qualitative data and descriptive statistical analysis and trend analysis	This study suggests significant health impacts on construction workers from heat stress exposure in the workplace, showed that heat stress levels were higher than those prescribed by international standards and highlights the need for revision of work practices increased protective measures, and possible development of indigenous work safety standards for heat exposure.
17	Venugopal et al. (2016a). The social implications of occupational heat stress on migrant workers engaged in public construction: a case study from Southern India	Both quantitative and qualitative studies	142 migrant workers	WBGT and questionnaires	Quantitative and qualitative analysis	In an increasingly warmer global climate and with increasing construction demand, stronger policies to prevent morbidity/mortality among vulnerable migrant workers in the construction sector is imperative. Better health, literacy rates, and decreased crime statistics among migrant community are potential positive implications of protective policies
18	Pradhan et al., (2013).Assessing climate change and heat stress response in the Tarai Region of Nepal	Case Study household survey	120 household factory workers	Data loggers, questionnaire and observation checklist	Comparative analysis of quantitative data	More quantitative measurement of workers' health effect and productivity loss will be of interest for future work
19	Xiang et al. (2015). Perceptions of workplace heat exposure and controls among occupational hygienists and relevant specialists in Australia	Cross-sectional research design	180 occupational hygienists	Questionnaire	Descriptive analysis using STATA and Excel	The findings suggest a need to refine occupational heat management and prevention strategies
20	Fleischer et al. (2013). Public health impact of heat-related illness among migrant farmworkers	cross-sectional survey research design	405 farmworkers	in-person interview	Statistical analysis using logistic regression	Migrant farmworkers experienced high levels of HRI symptoms and faced substantial barriers to preventing. Heat-Related Illness may be reduced through appropriate training of workers on HRI prevention, as well as regular breaks in shaded areas these symptoms

21	Mirabelli et al. (2010). Symptoms of heat illness among Latino farm workers in North Carolina	Cross-sectional study	300 farm workers	Interviewer-administered questionnaires	Descriptive statistical analysis using log-binomial regression	These findings suggest the need to improve the understanding of working conditions for farm workers and to assess strategies to reduce agricultural workers' environmental heat exposure
22	Ayyappan et al. (2009). Work-related heat stress concerns in automotive industries: a case study from Chennai, India	Quantitative research design		WBGT	Descriptive statistical analysis	The study re-emphasises the need for recognising heat stress as an important occupational health risk in both formal and informal sectors in India. Making available good baseline data is critical for estimating future impacts
23	Xiang et al. (2016). Workers' perceptions of climate change related extreme heat exposure in South Australia: a cross-sectional survey	Cross-sectional research study	479 workers	Questionnaire survey	Bivariate and multivariate analysis	Need to strengthen workers' heat risk awareness and refine current heat prevention strategies in a warming climate. Heat education and training should focus on those undertaking physically demanding work outdoors, in particular, young and older workers with low education
24	Lao et al. (2016). Working smart: An exploration of council workers' experiences and perceptions of heat in Adelaide, South Australia	A qualitative case study design	32 council male workers	focus groups	Thematic analysis and Interpretative Phenomenological Analysis	The results showed the importance of workplace management and training, and an understanding of the need for workers to be able to self-pace during hot weather
25	Mathee et al. (2010). Climate change impacts on working people (the HOTHAPS initiative): findings of the South African pilot study	Grounded theory	151 workers	Focus group discussion and interviews	STATA for quantitative data analysis and thematic analysis for qualitative data	People working in sun-exposed conditions in hot parts of South Africa currently experience heat-related health effect, with implications for their well-being and ability to work and that further research is warranted

Source: Reprinted from *Science of the Total Environment, 643*, Nunfam, V. F., Adusei-Asante, K., Van Etten, E. J., Oosthuizen, J., & Frimpong, K., Social impacts of occupational heat stress and adaptation strategies of workers: A narrative synthesis of the literature, 1542-1552, (2018), with permission from Elsevier.

Results of categorising and synthesising findings

Subsequently, the findings extracted were grouped into 11 categories (see Supplementary Figures 1 - 11) and synthesised into three main themes according to comparable and divergent patterns: 1) work-related heat stress risk; 2) social impact due to work-related heat stress; and 3) work-related heat stress adaptation (Fig's 1-3). Synthesis One describes work-related heat stress risk linked to workers and the workplace environment. It emerged from findings aggregated into categories (1 - 6) (Fig. 1). Social impact due to work-related heat stress, which constitutes Synthesis Two, was based on combining three groupings (7 - 9) (Fig. 2) while categories 10 and 11 were grouped into Synthesis Three (Fig. 3).

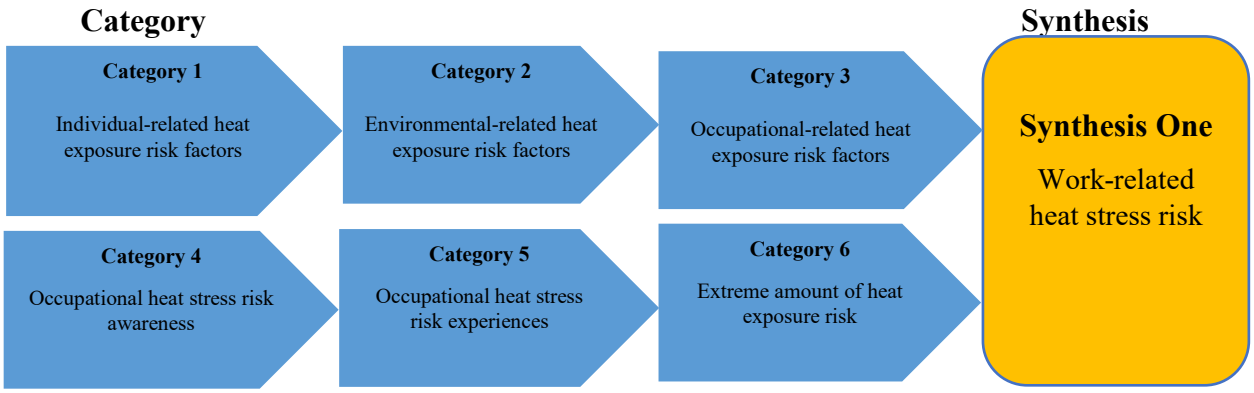

Fig. 1. Synthesis One: Work-related heat stress risk

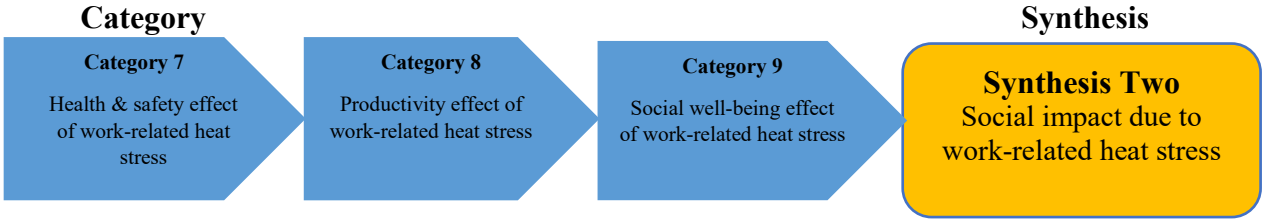

Fig. 2. Synthesis Two: Social impact due to work-related heat stress

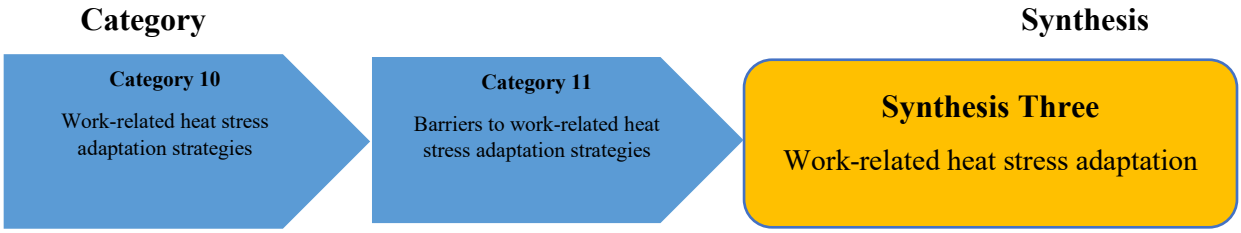

Fig. 3. Synthesis Three: Work-related heat stress adaptation

3. Conceptual perspective

The themes emanating from the synthesis served as the basis for the conceptual framework of the study. The framework provides a description and illustration of the social dimensions and impact trajectory of occupational heat exposure hazards associated with changing climate, adaptation strategies, and the SDGs (Figure 4). Vulnerability and risk of working populations to health hazards, loss of labour productivity and employment opportunities seem to be exacerbated by impacts of heat exposure (Ford et al., 2006; Lundgren et al., 2014). Climate change and occupational heat exposure impact poses a threat to the health, productivity and social lives of employees especially in low-and-middle income countries of tropical regions (Kjellstrom et al., 2011; Kjellstrom & McMichael, 2013; Kjellstrom et al., 2016b). These regions have inadequate adaptive capacity and inappropriate adaptation and social protection measures due to worsening poverty, insufficient resources, and lack of innovative technologies (Kjellstrom et al., 2016b; Lucas et al., 2014; Venugopal et al., 2016b).

The basic principle of vulnerability is that the extent of speed and severity associated with various forms of changes in climate conditions and heat exposure risks define the degree of susceptibility and risk of persons, social units, and communities. Similarly, the magnitude of coping, adaptation, and social protection strategies of climate change and occupation-related heat stressors to individual workers, social units, and communities determine the level of vulnerability

(Davidson et al., 2003; Davies et al., 2009; Ford et al., 2006; Kelly & Adger, 2000). Furthermore, education, poverty, gender inequality, infrastructure, food and nutrition, employment, income, livelihood, health, mobility, social services and institutional response as drivers of social, economic, and traditional developments also explain the magnitude of people's exposure and resilience to variations in climate conditions and hazards emanating from work-related heat stress (Ford et al., 2006; UN, 2011).

There are existing conceptual pathways that stipulate the dimensions, linkages, and impacts of heat exposure and risk factors on health, economic productivity, and in limited instances, on the social well-being of workers, as well as coping, social protection, mitigation and adaptation strategies to heat exposure and global climate change impacts on people (Berry et al., 2010; Frimpong et al., 2015; Haines & Patz, 2004; Kjellstrom & McMichael, 2013; Lucas et al., 2014; McMichael et al., 2006; Schulte & Chun, 2009). Thus, the application of the underlying ideas of the vulnerability and adaptation models to assess the risks and adaptive capacity of different cohorts of working populations, ecological units and systems, and communities to impacts of heat exposure and climate variation is not new (Crowe et al., 2010; Ford et al., 2006; Hanna et al., 2011; Xiang et al., 2016). Distinctively, the conceptual perspective as illustrated in the framework provides the basis for highlighting the link between heat exposure risk factors and occupational heat stress effects and the mediation role of adaptation strategies aimed at promoting the SDGs.

The various conceptual frameworks are comprehensive and valuable in explaining the scope, routes, and impacts of climate change-related hazards to human performance, health, productivity, communities, and ecosystems. However, concerns of social dimensions, linkages, and effects of climate change and occupational heat exposure effects on the healthiness, productivity, and social lives of workers and their families and communities appear to have been underestimated and/or

piecemeal in these models (Kjellstrom et al., 2016a; Kjellstrom et al., 2016b; Venugopal et al., 2016a). Hence, the necessity for a new conceptual framework describing the social dimensions and impacts of heat exposure, risk and effect of work-related heat stress on workers' health, productivity, social welfare, and adaptation policies in the perspective of the SDGs.

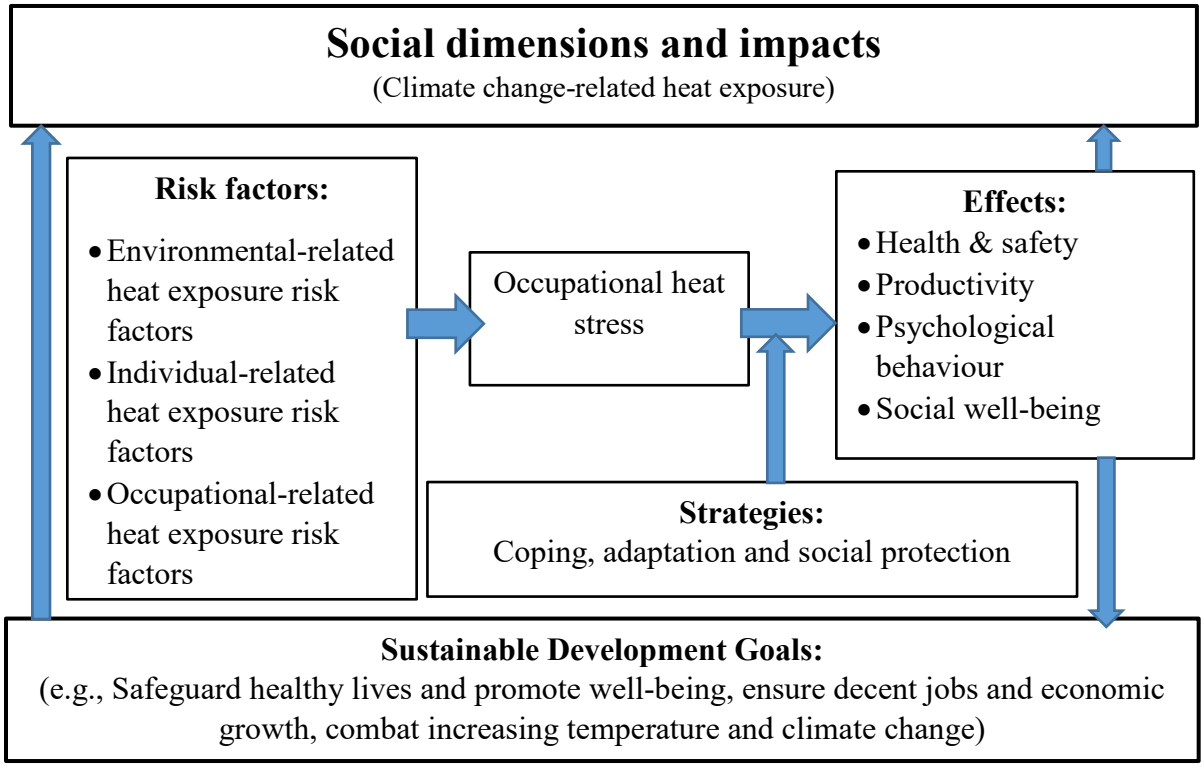

Figure 4: Social dimensions and impacts of climate change-related occupational heat stress and adaptation strategies: A conceptual framework

The proposed framework (Figure 4) operates on the assumption that the extent of work-related heat stress is linked to the intensity of heat exposure risk factors namely: 1) environmental-based heat exposure factors (e.g., temperature, air movement, humidity, and solar radiation); 2) occupational-related heat susceptibility factors (e.g., physical workload, clothing, work-break regimes, shade, cooling systems, type of work); and 3) individual-related vulnerability factors

(e.g., age, sex, body size, medical condition, medication, use of drugs and alcohol, rehydration, acclimatisation level, physical fitness, metabolism rate, choice of clothing, and prior heat injury). Consequently, occupational heat stress results in social implications associated with its physiological, health, psychological, behavioural, productivity, and social well-being effects on workers. The social repercussions of occupational heat stress in the form of illness, injuries, productivity losses, inadequate social welfare of workers in connection with their family relations, co-workers, and communities are interlinked. The social impact of heat stress on workers, workplace, and communities has implications for the realisation of the SDGs (Kjellstrom et al., 2016b). The effects of heat exposure as a result of current intensity and predicted rising temperature, precipitations, and droughts are reflective of the nature and characteristics of the environment, infrastructure, poverty, health and well-being, hunger, and food and nutrition related to the working population. Heat stress consequences arising from heat exposure has significant ramifications for the success of the SGDs. This further impacts on the extent of occupational heat exposure aggravated by climate change without adequate control measures and the cycle continues as indicated by the arrows (Figure 4). However, the social effects of heat stress linked to occupations on human performance, working populations, the environment, health, productivity, and economic output can be prevented and well managed. In addition to mitigation, impacts can be managed and ameliorated through appropriately improved policies of coping, adaptation and social protection, with the positive consequence of realising the SDGs.

Social dimensions and impacts of climate change-related heat stress of workers

The scope and spectrum of work-related heat stress effects from the perspective of climate change on workers in high danger of being exposed to heat include physiological, psychological,

behavioural, health and safety impact as well as social and productivity concerns (Dunne et al., 2013; Hanna et al., 2011; Kjellstrom et al., 2016a; Kjellstrom et al., 2009b; Nunfam et al., 2019a; Nunfam et al., 2019b; Venugopal et al., 2016a; Xiang et al., 2014a). Nonetheless, evidence of awareness and research accentuating the scope of social impact and the relationship between heat exposure concerns on safety, health, productivity, and adaptation policies for workers are inadequate (Kjellstrom et al., 2016a; Miller, 2014; UN, 2011; Venugopal et al., 2016a).

Recognised health impacts of morbidity and mortality linked with heat stress-related physiological disorders and its effect on people are varied (Kjellstrom et al., 2016a; Singh et al., 2013; Smith et al., 2014). Heat stress arises from the combined effect of intra-body heat beyond the core body temperature of 37 ^{o}C (Kjellstrom et al., 2016b). This results from physical workload, excessive outdoor ambient temperature, and clothing that prevents sweat evaporation and heat convection (Parsons, 2014). For instance, prolonged or short-term heat exposure coupled with inadequate dissipation of body heat results in direct heat-related illness described as heat rash, discomfort, and heat cramps (Kjellstrom & Crowe, 2011). It is also symptomatic of excessive sweating, headaches, dizziness, nausea, confusion, and weakness as a result of heat exhaustion, and heat stroke, that can be fatal. Heat is also connected to the danger of chronic illness and clinical damage to organ function including the risks of injuries and accidents (Bridger, 2003; CDCP, 2008; National Institute for Occupational Safety and Health (NIOSH), 2010). Hence, it is essential and timely to use the framework as the conceptual basis in future research and highlight evidence of the social dimensions and impacts of climate change-related health consequences on different worker cohorts.

Also, productivity impacts linked to heat stress experiences of workers have been acknowledged. Productivity hinges on temperature conditions when carrying out work which

requires physical exertion (Lloyd, 1994). Thus, working under excessive ambient temperatures of above 35-37 ^{o}C creates occupational heat-related health hazards, reduces productive capacity, and loss of labour productivity (Kjellstrom et al., 2016b). The natural protective response mechanism of a worker's body when working in a hot environment is to slow down work. This is to decrease metabolic heat production and thus reduce core body temperature. The response consequence is reduced productive capacity and loss of labour productivity (Dunne et al., 2013; Kjellstrom et al., 2009a; Parsons, 2014). Eventually, health impairment coupled with productive losses have the potential of adversely eroding workers' family income earnings through increased medical expenses, reduced economic output, and loss of employment opportunities (Kjellstrom et al., 2016a; Kjellstrom et al., 2016b; Venugopal et al., 2016a). Accordingly, labour productivity impacts have been estimated to lead to output reduction in affected sectors of over 20 percent throughout the subsequent part of the 20th Century, and worldwide economic cost of decreased productivity could be over two trillion USD by 2030 (IPCC, 2013). However, the extent of social impacts of productivity losses resulting from heat stress remains unanswered among various workers, particularly about mining workers and their families and communities.

Furthermore, unregulated core temperature beyond the body's tolerable limits and dehydration has been associated with adverse behavioural and psychological conditions. For example, adverse behavioural conditions (e.g., physical fatigue, prickliness, sluggishness, diminished vigilance, impaired judgment, and focus), and diminished visual alertness undermine work competence, occupational safety, health, and productivity (Kjellstrom et al., 2009a; Wyon et al., 1996). Similarly, easy exhaustion and self-pacing are behavioural changes connected to heat stress, which often results in reduced capacity, productivity losses, and increased risks of accidents and injuries (Singh et al., 2013; Xiang et al., 2014b). Psychologically, fear of accidents,

injuries, increased irritation and decreased vigilance linked to heat stress also influence mental well-being and impede hands-on dexterity, and productive capacity leading to productivity losses (DeVries & Wilkerson, 2003; Lundgren et al., 2013). However, the extent of these social impacts and implications associated with adverse behavioural and psychological repercussions of heat stress on different workers are piecemeal and without adequate research evidence.

Finally, workers' social lives, comfort and cohesion are affected by work-based heat stress. Not only does heat-related illness and productivity loss result in income erosion and loss of occupation but it also influences the social health and cohesion of workers, their families, co-workers, and communities (Miller, 2014; Venugopal et al., 2016a). More so, tiredness, sickness, and workplace stress and frustration expressed in alcoholism, smoking, substance abuse, and workplace violence lead to interpersonal issues with colleagues, subordinates, and supervisors. It also results in domestic violence and disrupted family life in the form of loss of leisure, loss of family income, increased medical expenses, and increased risk to family education, health, and social cohesion and well-being at the community level because of aggravated poverty, inequality, domestic violence, and suicide (Miller, 2014; Venugopal et al., 2016a).

4. Workers' adaptation strategies to work-related heat stress driven by climate change

The social dimensions of exacerbating impacts of heat stress could potentially undermine the capacity of workers. The socioeconomic and health ramifications of occupational heat stress on working populations are substantial. Therefore, various conceptual and empirical schemes of preventive and control strategies to protect workers against heat stress hazards have been identified. The essence is to decrease exposure to heat hazard, boost resilience and adaptive capacity of workers, including their family members and social groups to ensure viable well-

being. Investing and implementing strategies (e.g., social protection, adaptation and mitigation) are identified as workable in work-related heat stress prevention and control measures (Nunfam et al., 2019a; Venugopal et al., 2016a; Venugopal et al., 2015; Xiang et al., 2016). Obligations to international protocols underscore the necessity for preventive and control actions to heat stress (IPCC, 2014; Rhodes, 2016; Rogelj et al., 2016). Based on these protocols, policy frameworks, programmes, and targets have been outlined to reduce vulnerability, hazards and exposure to heat as the world experiences climate change. It is also to boost workers' resilience and adaptive capability (Rhodes, 2016; World Meteorological Organisation [WMO] & World Health Organisation [WHO], 2015). Accordingly, the conceptual perspective, as highlighted in the framework, can shape future studies in providing evidence of coping, adaptation and social protection strategies aimed at informing heat stress management protocols, actions and policy decisions.

By priority, it is advocated that effects of heat stress due to increasing temperature in the context of global warming on workers should be significantly reduced through shared global regulation of human-induced GHG emissions (IPCC, 2015; Lundgren et al., 2013). However, at more local scales, healthy and productive adaptation and social protection strategies for working and living in warmer environments are also needed (Frimpong et al., 2015). Adaptation involves minimising actual workplace heat exposure, avoiding heat stress, and protecting workers from occupational heat exposure. Social protection involves collective and individualised strategies, programmes, and actions directed at averting, decreasing, and eradicating poverty, and social marginalisation. It also seeks to boost prospects and resilience by stimulating social capital of workers to ensure decent and productive employment (Cichon, 2013; Mundial, 2012; UNICEF, 2012).

The impact of heat stress related to occupations because of climate change on workers' social welfare, productivity, and health remains critical. However, the application of mitigation, coping, adaptation, and social protection policies as sustainable alternatives in preventing and controlling risks and vulnerabilities to excess poverty and socioeconomic exclusion related to climate change are not exclusive (Davies et al., 2009; Kjellstrom et al., 2016a; Kjellstrom et al., 2009b; Venugopal et al., 2016a; Venugopal et al., 2016b). Generally, preventive and control intervention of heat exposure comprise managerial controls, engineering designs, and continued training and education regimens. It also involves social safety mechanisms, consolidation of guidelines, changing economic systems to indoor work, and providing reparations for productivity losses of workers (Kjellstrom et al., 2016b; Lucas et al., 2014; Lundgren et al., 2013; UN, 2011).

Innovatively designing and regulating workers' resting and workplace environments, plants, equipment, ventilation systems and processes help in avoiding, adjusting, and reducing the impacts of heat stress exposure. Engineering controls enhance cooling and air circulations, insulations, access to adequate shade, worker rehydration, and protective clothing. However, inadequacies of engineering controls, have necessitated the use of administrative control mechanisms through worker practice and monitoring systems. These are exemplified in work-rest regimes, self-pacing, shift work schedules, hazard alerts, acclimatisation regimes, and biophysical monitoring (Kjellstrom et al., 2016b).

Furthermore, regular information, education, communication, and awareness campaigns, including training programmes, enhance the prevention and control of heat stress impacts. Also, improving the preventive and control intervention of climate change-related heat stress by strengthening labour organisations, regulations and workers' protective policies have implications for work-related heat stress. Similarly, it is advocated that direct effects of work-related heat stress

in the form of illness, injuries, income losses, and social disruptions of workers are compensated (Kjellstrom et al., 2016b; Lundgren et al., 2013).

Besides, workers' vulnerability is reduced, and their resilience and adaptive capacity enhanced by social protection and insurance policies, programmes, and strategies (e.g., social security, superannuation, pension schemes). Also, health insurance, interventions to employment market (e.g., standards for employment, regulation to protect workers interest, minimum wage policy), and humanitarian relief and aids to workplace disasters are valuable strategies (Davies et al., 2009). Another measure with the possibility of indirectly preventing and controlling the impact of heat stress relates to fiscal and regulatory mechanisms of accelerating the pace of transforming the structure of economies with a focus on industries involving non-outdoor working environments such as service and industrial sectors (Frimpong et al., 2015; Kjellstrom et al., 2016b).

However, these preventive and control mechanisms are somehow inadequately and inequitably implemented without recourse to adequate global collaboration of developed and developing nations in the era of worsening and unavoidable heat exposure. It is, therefore, imperative to use the framework as the basis to investigate and highlight the social implications of coping, adaptation and social safeguard policies of workers to the impact of work-related heat stress particularly amongst worker cohorts of various industries.

5. Conclusions and implications for policy and research

The conceptual framework developed here based on the relevant literature shows that the social dimensions and potential effects of heat stress on occupations relate to workers' productive capacity, health and safety, psychological behaviour, and social lives and well-being. The

framework also demonstrates that the risks and impacts of work-related heat stress hinge on the extent of employees' susceptibility and adaptive capacity and which has implication for the realisation of the SDGs. This is derived from the principle that a worker's exposure and sensitivity to the danger and impact of work-related heat stress is positively related to the worker's state of susceptibility and negatively related to the worker's adaptive capacity and resilience. Similarly, concerns of social dimensions and occupational heat stress impacts on workers seem to receive little attention in empirical, review and conceptual studies. It is also overlooked in social impact and climate change discourse, even though, it has implications for ecological, socioeconomic and human health.

The essence of the focus on the social dimensions of work-based heat stress and climate change is to contribute to the ongoing discourse, policy and research effort on climate change to ensure an inclusive sustainable development to overcome poverty, ensure healthy lives, combat increasing ambient temperature, and promote decent jobs. This has the possibility of facilitating environmental justice and decreasing the vulnerability of people including worker cohorts, improving their adaptive capacity and resilience as well as their productive capacity and social well-being for social and economic growth and development. The research and policy implication is that ecological, social risk, and environmental health scientists as well as governments in developing countries, for instance, would need to promote research, socially inclusive, climate resilient policies and operations to improve progress towards the SDGs. Thus, significant and sustained global collaborative effort, financial support for research and development, improved social protection and adaptation policies can reduce exposure and boost the resilience and adaptive capacity of workers to facilitate the global achievement of the SDGs.

Acknowledgements

We acknowledge the support of the ECU Higher Degree by Research Scholarship (HDRS) for the provision of a PhD scholarship and the Human Research Ethics Committee of ECU (Project Number 17487) for ethical clearance.

Conflict of interest

None

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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