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Climate change and occupational heat stress risks and adaptation strategies of mining workers: Perspectives of supervisors and other stakeholders in Ghana

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ABSTRACT

Increasing air temperatures as a result of climate change are worsening the impact of heat exposure on working populations, including mining workers, who are at risk of suffering heat-related illnesses, injury and death. However, inadequate awareness of climate change-related occupational heat stress risks and adaptation strategies have been shown to render occupational heat stress management ineffective. A concurrent mixed-methods approach was used to assess the perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers among supervisory personnel and other stakeholders in Ghana. Questionnaires and interviews were used to elicit data from 19 respondents. Data were processed and interpreted using descriptive statistics, chi-square and Fisher's exact tests, and thematic analysis. Supervisors' climate change risks perception was adequate, and their concern about workplace heat exposure risks was moderate. Mining workers' occupational heat stress risks experiences were linked to heat-related illness and minor injuries. Mining workers' adaptation strategies included water intake, use of cooling mechanisms, work-break practices, and clothing use. The related differences in job experience in the distribution of climate change risk perception and occupational heat stress risk experiences, and the difference in educational attainment in the distribution of adaptation strategies of occupational heat stress were significant ($p < 0.05$). Hence, an effective workplace heat management policy requires adequate understanding of occupational heat stress risks and adaptation policies and continued education and training for mining workers.

1. Introduction

Occupational heat exposure due to rising temperature and climate change has emerged as a threat to the health and safety, productivity, and social well-being of diverse working population in the world (Kjellstrom et al., 2016a, 2016b; United Nations (UN), 2009). For this reason, the essence of the 2030 Sustainable Development Goals (SDGs) is to guarantee healthy lives, promote well-being, ensure decent jobs and work capacity, and to combat intensifying temperature and climate change impacts (Leal Filho et al., 2018; Xue et al., 2018; United Nations (UN), 2015).

In Ghana, direct signs of climate change impacts are associated with increasing temperature, rainfall variability, extreme weather events (e.g., storms and floods) and sea level rise. For instance, in four decades (1960–2000), Ghana has broadly experienced an increase in mean temperature of around 1 °C since 1960 at an average rate 0.21 °C per decade (Government of Ghana, 2013, 2015). The average temperature is expected to rise by further 0.6 °C, 2.0 °C, and 3.9 °C in 2020, 2050, and 2080 respectively (Government of Ghana, 2013, 2015). Similarly, while rainfall levels have been reducing and becoming increasingly erratic, sea levels have risen by 2.1 mm per year over the four decades. Consequently, sea levels are projected to increase by 5.8 cm, 16.5 cm, and 34.5 cm in 2030, 2050, and 2080 respectively. Also, Ghana's total net Greenhouse Gas (GHG) emissions including Agriculture, Forestry and other Land Use (AFOLU) has increased from 14.22 million tons (Mt) CO_2-equivalent (CO_2e) in 1990–33.66 MtCO_2e in 2012 (Government of Ghana, 2013, 2015). Like most countries in the tropical and sub-tropical regions of the world, climate change is worsening the

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impact of excessive heat exposure on workplace environments and puts outdoor physical workers including, but are not limited to, mining workers in Ghana at risks of heat stress (Frimpong et al., 2017; Xiang et al., 2016). Working in hot weather conditions without adequate mitigation, adaptation and social protection may significantly result in increases in heat-related illness and injuries, absenteeism, slow work pace, loss of productive capacity, and poor social well-being (Kjellstrom et al., 2016a; Nunfam et al., 2018).

Impacts of occupational heat stress (e.g., heat-related illness and injuries) are avoidable and controllable. Adequate awareness, knowledge and understanding of risks associated with climate change and occupational heat stress is a substantial part of heat stress management strategies (e.g., mitigation, adaptation and social protection policies). However, ineffective and unsustained heat stress management strategies due to weak and uncoordinated effort among stakeholders (e.g., government agencies, occupation health and safety service providers, employers, employees, and worker unions) are noticeable (Xiang et al., 2015b). Part of the gap relates to less concerns, varying knowledge and inadequate awareness of climate change-related occupational heat stress risks and adaptation strategies among workers, their supervisors and regulatory authorities (Balakrishnan et al., 2010; Crowe et al., 2010; Mathee et al., 2010; Stoecklin-Marois et al., 2013). Also, perception of temperature and climate change concerns, and the distress about its occurrence are positively associated (Li et al., 2015; Searle and Gow, 2010). But links between climate change concerns and heat stress, and perception of temperature and heat stress are less understood (Zander et al., 2017).

In particular, significant stakeholders (e.g., occupational health and safety managers, unionised interest groups, and regulatory authorities) at the forefront of occupational health and safety in Ghana's mining industry are significant actors in protecting and safeguarding workers' health, safety, productive capacity and social well-being. Not only do such stakeholders have the mandate of identifying, evaluating and controlling environmental and workplace-related hazards, but they are also responsible for monitoring, training and educating, prescribing important guidelines on heat stress management to workers. Perspectives of supervisors and other stakeholders on occupational heat stress risks and adaptation strategies of mining workers in the context of climate change in Ghana's mining industry is therefore valuable and timely. Hence, we sought to determine what are the perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers among these supervisory personnel and other stakeholders? We also sought to test the hypothesis that there are no significant differences in the distribution of climate change risks perceptions, occupational heat stress risks, and adaptation strategies among background characteristics of the supervisory personnel.

2. Material and methods

In cognisance of the pragmatist methodological viewpoint, the concurrent mixed methods research strategy involving a descriptive cross-sectional survey was employed to provide a holistic understanding of the research problem (Creswell, 2002, 2013; Neuman and Kreuger, 2003; Neuman and Robson, 2012; Sarantakos, 2012). The mixed method was deemed appropriate to provide a complementary and corroborative analysis and understanding of multiple data (both quantitative and qualitative) on climate change risk perceptions, occupational heat stress risks, and adaptation strategies of mining workers among supervisors and stakeholders. The sample size (19) respondents consisted of 16 supervisory personnel (e.g., workplace hygienists; health, safety, and environmental officers) and three officials of the other (external) stakeholders (Ghana Chamber of Mines[GCM]; Inspectorate Division of the Minerals Commission [IDMC]; and Ghana National Association of Small Scale Miners [GNASSM]) of Artisanal Small Scale and Large Scale Mining Companies in Ghana. Purposive sampling was used to identify and select the participants with the knowledge and experience of the phenomenon of interest, after expressing their willingness to participate in the study based on informed consent (Bernard, 2017; Creswell and Clark, 2017). The participants were selected because they were directly responsible for overseeing and regulating the activities of mining workers and companies to ensure a decent, healthy and safe working environment. Participants also had the requisite professional competence, knowledge and experience beside the required depth of information related to issues of occupational health and safety, environmental hazards, and adaptation strategies of workers in the mining industry in the context of climate change.

Questionnaires and in-depth interviews were used in accessing data from the supervisory personnel and other stakeholders respectively on their perspectives of climate change risks, experiences of occupational heat exposure risks, and adaptation strategies of mining workers. The questionnaires were deemed suitable for the supervisory personnel because they were literate. In-depth interviews were used for the other stakeholders because of the need for detailed information. The content and design of the instruments was guided and adapted from the validated instruments used in the High Occupational Temperature Health and Productivity Suppression (HOTHAPS) programme and other studies related to peoples' perception of climate change, heat stress vulnerability, and its impacts on health, productivity, social lives, and adaptive capacity of workers (Kjellstrom, 2012; Kjellstrom et al., 2009a; Sheridan, 2007; Xiang et al., 2015b). The questions focused on perceptions and experiences of climate change and heat exposure risks, workplace health and safety policies and regulations governing working in hot environments, heat stress and climate change adaptation policies. The feasibility of the modified instruments (both open-ended and closed-ended question items) was pretested for clarity in Ghana after it was reviewed by experts from Edith Cowan University (ECU) to ascertain further validity and reliability. The fieldwork was conducted from October 2017 to December 2017. Most aspects of the data were collected during the 2017 National Inter-Mines First Aid and Safety Competition in Ghana, held from 12/11/2017 to 18/11/2017 under the theme: 'Safe and Responsible Mining! Our Heritage'. The fieldwork was preceded by the acquisition of ethical clearance from the Human Research Ethics Committee of ECU (Project Number 17487).

The qualitative data was organised with NVivo version 11 while the quantitative data were processed with the use of Microsoft Excel 2016 and IBM Statistical Product and Service Solutions (SPSS) version 24 to facilitate data analysis. Thematic analysis was employed to summarise the qualitative aspect of the data in the form of text, quotes and extracts based on emerging themes (Ritchie et al., 2013). The themes ensured easy description and interpretation based on relationships and differences in perceptions of climate change risks, experiences of occupational heat exposure risks, and adaptation policies. The quantitative data were analysed using descriptive statistics (e.g., minimum, maximum, frequency and percent), tables and charts. The Chi-square (x^2) and Fisher's Exact tests were employed to test the hypothesis at the level of significance ($p < 0.05$). In social science research, the x^2 and Fisher's Exact test are commonly used in statistical analyses to assess the probability of difference or association or independence between categorical variables (Franke et al., 2012; McHugh, 2013). The Yates' Continuity Correction, Likelihood Ratio, and Fisher's Exact test results were reported where assumptions of the x^2 test were violated (Agresti, 1996; Fisher, 1935; McHugh, 2013; Pallant, 2010; Yates, 1934).

3. Results and discussion

Based on the mixed methods approach, results of the survey on the supervisory personnel were complemented by views of the other stakeholders. The results were also related to the relevant literature (e.g., reports, conceptual and empirical data) to provide comprehensive information and understanding of the perceptions of climate change and heat exposure risk concerns for adequate adaptation policy decisions in the mining industry.

Table 1
Background characteristics of respondents (n = 16).
Source: Field survey, 2017.

Background characteristics	F	%
Type of mining:		
Small-scale mining	7	43.8
Large-scale mining	9	56.2
Sex:		
Male	15	93.7
Female	1	6.3
Age:		
31–40	10	62.4
41–50	5	31.3
51+	1	6.3
Education:		
Undergraduates	7	43.8
Graduate	9	56.2
Years of OH&S working experience:		
0–4	2	12.5
5–9	1	6.3
10+	13	81.2

3.1. Background characteristics

Table 1 shows the respondents' background characteristics. The results of the study revealed that 56.2% of the supervisory personnel were from large-scale mining companies, 93.7% were males, and the majority (62.4%) were within the ages of 31–40 years old. Also, 56.2% had graduate degrees, and 81.2% had over ten years of working experience in occupational health and safety (OH&S).

Pseudonyms (KS1, KS2 & KS3) were used to de-identify and report the views of the three stakeholders to ensure confidentiality. Officials who represented the three stakeholders in the in-depth interviews consisted of a research and analysis officer (KS1), director of operations (KS2) and a principal mine inspector (KS3). KS1 was responsible for health and safety policy advocacy and had a postgraduate degree and four years of working experience. KS2 was responsible for overseeing and coordinating the activities of SSM companies and had an undergraduate degree and five years of working experience and KS3 was responsible for enforcing mining laws, regulations and standards and had a first degree in mining and 10 years of working experience in the mining industry.

3.2. Perceptions of climate change risks

Comparatively, the findings on varying and adequate awareness identified from this survey were reasonably similar to the views expressed during the in-depth interviews in similar studies found in the literature (e.g., Baptiste, 2017; Brechin and Bhandari, 2011; Lee et al., 2015; Pugliese and Ray, 2009;Thomas and Benjamin, 2018). The results of this study on the perceptions of climate change risks showed that all the supervisory personnel (Table 2) and the other stakeholders were adequately aware of the changes in patterns of climate conditions over the last three decades. For instance, one of the other stakeholders said:

> *Yes, we are all very much conversant with the issue of climate change, but we need to contextualise the change in weather pattern based on the location of the mines … they are also experiencing some variations of the weather pattern (KS1).*

Another stakeholder commented that:

> *I have heard of weather changes, yes of course from the media, and other sources. Yes, I know that there have been changes, ocean levels are rising. I also know of the ozone layer depletion in certain parts of the world. In Ghana, for example, I know our weather system have shifted somehow (KS2).*

Lower levels of climate change awareness were reported in Asia, the Middle East, North African and Sub-Saharan African regions (Pugliese and Ray, 2009). However, the findings related to climate change awareness in this study are more in line with the higher levels of climate change awareness and risk perception reported in regions of Europe, Japan and North America as well as other studies (Brechin and Bhandari, 2011; Lee et al., 2015; Neely, 2012; Pugliese and Ray, 2009). Adequate and sustained adaptation policies to climate change depend on workers' perceived and actual knowledge, awareness and understanding of climate change and heat exposure risks (Ford et al., 2010; Kjellstrom et al., 2016b; Tripathi and Mishra, 2017).

Table 2
Perceptions of climate change risks based on the frequency of responses (n = 16).
Source: Field survey, 2017.

Awareness and concerns	F	%
Awareness of climate change:		
Yes	16	100
No	0	0
Signs of climate change (n = 61[a]):		
Increase in temperature and hot environment	12	19.7
Irregular rainfall and storms	16	26.2
Frequent floods	7	11.5
Prolong drought	3	4.9
Rising sea level	12	19.7
No response	11	18
Mining workers at risk of workplace heat exposure due to climate change:		
Yes	12	75
No	4	25
Environmental factors influencing workplace heat exposure (n = 45[a]):		
How hot the air is around the workplace	12	26.8
The amount of air moisture in outdoor setting/workplace	11	24.4
Heat radiation from the sun and other sources around the workplace	11	24.4
No response	11	24.4
Work-related factors influencing heat exposure(n = 77[a]):		
Type of physical workload	14	18.2
Duration of working hours	11	14.3
Type of protective clothing	11	14.3
Access to cooling systems (e.g., air conditions & fans)	9	11.7
Duration of break/rest hours	6	9.0
Access to shade	4	5.2
Access to drinking water	8	10.4
Type of clothing	2	2.6
No response	11	14.3
Extent of concern about workplace heat exposure:		
Not at all concerned	1	6.3
A little concerned	3	18.8
Moderately concerned	8	56.3
Very much concerned	3	18.8

[a] Multiple responses.

The opinions identified from the survey was primarily informed by increases in temperature and hot environment (19.7%), irregular rainfall and storms (26.2%), and rising sea levels (19.7%) (Table 2) as observed signs of climate change risk. Similarly, rising temperatures, humid and sunny weather conditions, unpredictable rainfall and rising ocean levels emerged as signs of climate change during the in-depth interviews with the other stakeholders. For example, a stakeholder observed that: 'the signs you see is the humid conditions, the sunny and the hot weather conditions' (KS3). Another stakeholder was of the view that:

> *In the past, we had a very defined period for our rainy seasons and the dry seasons, which are the two main seasons within the country, but now you cannot predict with certainty. You have rains during the dry seasons, and even in the rainy seasons, the rains may not come as expected. So it has made us revise our weather patterns (KS1).*

The findings related to signs of climate change risk reiterates similar results of various studies in which increasing temperatures, changes in precipitation patterns, changing humidity, sea level rise, and storm surges were identified as anthropogenic climate change risks (Evadzi

Table 3
The difference in the distribution of climate change risks perception among background characteristics of supervisory personnel of mining workers (Chi-square test). Source: Authors, 2017.

Background characteristics	Perceptions of climate change risks									
	Signs of climate change		Workers at risk of workplace heat exposure		Environmental factors influencing workplace heat exposure risk		Work-related factors influencing workplace heat exposure risk		Concerns about workplace heat exposure/heat stress risk	
	n (%)	p-value	n (%)	p-value	n (%)	p-value	n (%)	p-value	n (%)	p-value
Type of mining:		0.962		0.585		0.672		0.064		0.438
SSM	7(43.8)		7(43.8)		7(43.8)		7(43.8)		7(43.8)	
LSM	9(56.2)		9(56.2)		9(56.2)		9(56.2)		9(56.2)	
Years of OHS work experience:		0.012*		0.007*		0.004*		0.020*		1.000
Under 10 years	3(18.8)		3(18.8)		3(18.8)		3(18.8)		3(18.8)	
10 years and over	13(81.2)		13(81.2)		13(81.2)		13(81.2)		13(81.2)	
Level of education:		0.720		0.585		0.137		0.201		0.438
Undergraduate	7(43.8)		7(43.8)		7(43.8)		7(43.8)		7(43.8)	
Graduates	9(56.2)		9(56.2)		9(56.2)		9(56.2)		9(56.2)	

et al., 2018; Hoogendoorn and Fitchett, 2018; van Oldenborgh et al., 2018). Similarly, in most tropical regions like Ghana, climate change risk is epitomised by variations in average temperature, precipitation, and wind conditions ascribed to increases in GHG (e.g., CO_2 and methane) emissions due to human activities (Government of Ghana, 2013, 2015). The perceptible variability of natural climate or extreme weather events (e.g., heat waves, high temperatures, erratic rainfall, drought, relative humidity, and sea levels) usually occur over a decade (UNFCCC, 2010). These weather-related conditions are regarded as immediate factors of social vulnerability and risks of climate change (UNFCCC, 2010; United Nations (UN), 2011).

Also, 75% of the respondents were of the view that due to climate change mining workers were at risk of workplace heat exposure. Similar views expressed by the stakeholders showed that mining workers were at risk of workplace heat exposure. For instance, one stakeholder indicated that:

> *The mining workers are at risk of heat exposure when they remain in that condition for a longer period. That is, in that humid or hot weather conditions for longer period.… so we have to get some mitigation measures to put in place to avoid this heat stress and then exhaustion and the rest (KS3).*

It was also observed by another stakeholder that:

> *If there is a large amount of rain, it slows down the mining activities. The dry season is very good for mining.…, but it's not good for the individuals [workers] because it leads to the rapid dehydration of the individual and it can lead to the potential of people collapsing and fainting or even getting exhausted very quickly because of the dry, humid and hot weather condition (KS1).*

The workplace heat exposure was attributed to environmental factors such as the extent of hot air around workplaces (26.8%), the amount of air moisture in outdoor setting or workplaces (24.4%) and heat radiation from the sun and other sources around the environment (24.4%). Work-related conditions such as the type of physical workload (18.2%), duration of work (14.3%), type of protective gear (14.3%), access to cooling systems (e.g., fans & air conditions), and drinking water were also perceived as contributory factors to heat exposure (Table 2).

The findings of the study that ascribed workplace heat exposure risk to environmental and work-related factors were supported by the view that heat exposure risk is associated with exposure factors such as environmental, personal, and occupational-related heat risks. Factors related to the environment are influenced by a combination of higher ambient temperatures, radiant heat and relative humidity, often accompanied by calm days with reduced air flow (Kjellstrom et al., 2009b; Schulte and Chun, 2009). The occupational-related heat exposure factors include clothing type, physical activity, cooling system, work-rest regimes, break hours, access to shade and drinking water, and the personal related factors include age, sex, body size, pre-existing disease, acclimatization, type of work, lifestyle, medication, drugs, and alcohol (Haines and Patz, 2004; Kjellstrom et al., 2016a; McMichael et al., 2006; Parsons, 2014).

Given the extent of climate change risks awareness, 56.3% of respondents were moderately concerned about heat stress-related morbidity and mortality associated with workplace heat exposure conditions in the mining sector (Table 2). In a similar study of perceptions of workplace heat exposure and controls among occupational hygienists and relevant specialist in Australia, most respondents (90%) were at least moderately concerned about extreme heat exposure (Xiang et al., 2015b). Also, a survey of mining sector practitioners in Canada found that the respondents were somewhat concerned about future climate change impacts (Ford et al., 2010).

Considerably, individual and social awareness of climate change and perception of its risk constitute an essential part of informing policy decisions and improving climate change risk information and communication (Aswani et al., 2015; Carlton and Jacobson, 2013; Hagen et al., 2016). Hence, the awareness and understanding of the supervisory personnel and stakeholders' perceptions about climate change risk are important for policymaking, risk communication and critical to any strategic response to combating climate change impacts (Carlton and Jacobson, 2013; Lorenzoni and Pidgeon, 2006).

The results of the x^2 test for differences in the proportion of perceptions of climate change risks among background characteristics of the supervisory personnel are illustrated in Table 3. The differences in distribution of climate change risks perceptions based on the signs of climate change ($x^2(3) = 0.290$, $p = 0.962$), workers at risks of workplace heat exposure ($x^2(1) = 0.085$, $p = 0.585$), environmental factors ($x^2(2) = 0.796$, $p = 0.672$), work-related factors ($x^2(4 = 8.885$, $p = 0.064$), and concerns about workplace heat exposure ($x^2(1) = 0.017$, $p = 0.438$) between categories of type of mining were not significant at alpha level of 0.05 (Supplementary Tables 1–5). Also, the differences in proportion of climate change risks perceptions based on the signs of climate change ($x^2(3) = 1.337$, $p = 0.720$), workers at risks of workplace heat exposure ($x^2(1) = 0.085$, $p = 0.585$), environmental factors ($x2(2) = 3.971$, $p = 0.137$), work-related factors ($x^2(4) = 5.974$, $p = 0.201$), and concerns about workplace heat exposure ($x^2(1) = 0.017$, $p = 0.438$) between categories of level of education were not significant at alpha level of 0.05 (Supplementary Tables 6–10).

However, the differences in distribution of climate change risks perceptions based on the signs of climate change ($x^2(3) = 10.944$,

Table 4
Experiences of occupational heat stress risk (n = 16).
Source: Field survey, 2017.

Experience of occupational heat stress	F	%
Workers concerns about heat exposure at workplace:		
Yes	14	87.5
No	2	12.5
Heat-related illness concerns (n = 51[a]):		
Excessive sweating	13	25.5
Headaches	9	17.6
Heat exhaustion/tiredness	3	5.9
Heat rash	8	15.7
Heat syncope(fainting)	7	13.7
No response	11	21.6
Heat-related injury concerns:		
Yes	9	56.3
No	7	43.8
Extent of injury:		
Minor	5	55.6
Moderate	4	44.5
Type injury concerns (n = 23[a]):		
Burns from hot objects/surfaces	5	21.7
Falls, trips, and slips due to dizziness, fainting and fatigue	5	21.7
Being hit by objects	2	8.8
No response	11	47.8
Witnessed heat-related injury to mining workers:		
Yes	6	37.5
No	10	62.5
Type of injury witnessed (n = 18[a]):		
Burns from hot objects/surfaces	3	16.7
Falls, trips, and slips due to dizziness, fainting and fatigue	2	11.1
Loss of grip and controls due to sweaty hands	1	5.6
Being hit by objects	1	5.6
No response	11	61.1

[a] Multiple response.

$p = 0.012$), workers at risks of workplace heat exposure ($x^2(1) = 6.701$, $p = 0.007$), environmental factors ($x^2(2) = 10.944$, $p = 0.004$), and work-related factors ($x^2(4) = 11.623$, $p = 0.020$) except concerns about workplace heat exposure ($x^2(1) = 0.000$, $p = 1.000$) between the categories of years of OHS work experience were statistically significant at alpha level of 0.05 (Supplementary Tables 11–15). Thus, while the differences in the distribution of climate change risks perceptions between the categories (type of mining and level of education) were not significant, the differences in the distribution of climate change risk perceptions between the categories of years of OHS work experience were significant at the level ($p < 0.05$).

3.3. Experiences of occupational heat stress risk

We found that workers' experiences of heat-related illnesses and injuries were associated with workplace heat exposure as shown in the literature (Balakrishnan et al., 2010; Stoecklin-Marois et al., 2013; Xiang et al., 2015a, 2016). Table 4 presents the experiences of occupational heat stress risks of mining workers as described by supervisors of the respondents involved in this research. Eighty-seven percent of supervisory personnel were of the view that, in their respective working experience, mining workers had expressed concern about workplace heat exposure during hot weather conditions. Hence, heat-related illness concerns most frequently expressed by mining workers included excessive sweating (25.5%). This was followed by headaches (17.6%), heat rash (15.7%), fainting (13.7%), and heat exhaustion or tiredness (5.9%). Similarly, empirical evidence (e.g., in Australia, Southern India, California, and South Africa) confirms the view that mining workers were concerned about workplace heat exposure and its associated illness and injury conditions (Singh et al., 2015; Stoecklin-Marois et al., 2013; Xiang et al., 2016). Specific studies related to mining workers also substantiates comparable experiences of heat-related illness concerns among surface and underground mining workers in US and Australia (Donoghue, 2004; Donoghue et al., 2000; Hunt, 2011).

Furthermore, views akin to heat tiredness, fainting, excessive sweating and dehydration were expressed by other stakeholder interviewees as heat-related illness concerns of mining workers as exemplified in the following statements:

> *What is quite popular is the exhaustion, of course, it may lead to the person fainting, collapsing etc. So there is a risk that you [worker] may be dehydrated. So water has been provided at point A, B or C to make sure you [worker] drink water from time to time on a regular basis. If for some reasons you [worker] think you are dehydrated and need a break (KS1).*

> *That is why we ensure that where you [workers] are working you don't have poor ventilation. If you experience excessive sweating, you have to report to the supervisor. What is guiding the regulation is that at first, we were experiencing these heat stress and heat strokes, so the regulations seek to address all these challenges so that they don't encounter such situation again (KS3).*

> *Yes, excessive sweating. There have been some experiences of headaches, but may be not to the extent of dehydration because the workers drink a lot of water when on site compared to when they are in the house (KS2).*

In addition, 56.3% of the supervisory personnel indicated that mining workers had some form of heat-related injury concerns in their workplaces or workplaces where they had consulted during hot weather conditions. However, unlike studies in Thailand and Southern Australia (e.g., Tawatsupa et al., 2013; Xiang et al., 2016), the magnitude of occupational heat-related injuries was described by 55.6% of the respondents as minor injury conditions other than moderate, serious, severe, or critical injury conditions. Also, falls, trips, and slips due to dizziness, fainting and fatigue were indicated by 21.7% of the respondents as the common cause of the injuries aside from burns (21.7%) and being hit by objects (8.8%). As substantiated in other studies, the findings based on occupational heat-related injury concerns have been linked to workplace heat stress due to extreme heat exposure. For instance, heat stress is associated with occupational injury concerns in tropical Thailand and Southern Australia under extreme heat exposure (Tawatsupa et al., 2013; Xiang et al., 2016). As to whether the supervisory personnel had ever witnessed any form of heat-related injury to mining workers, 37.5% answered in the affirmative. Moreover, 16.7% associated such injuries to burns from hot surfaces and objects and 11.1% linked the injuries to falls, trips, and slips due to dizziness, fainting and fatigue (Table 4).

The knowledge and experiences of occupational heat stress risk concerns of mining workers, as corroborated by climate change reports in Ghana and other studies, highlights the growing impact of heat exposure as a result of rising temperature and climate change, extreme weather events, GHG emissions and loss of carbon sinks (Government of Ghana, 2013, 2015; Xiang et al., 2016). Occupational heat stress risks and impacts possess the tendency of affecting workers' health and safety, productive capacity, efficient performance, and social well-being (Kjellstrom et al., 2016b; Nunfam et al., 2018; Venugopal et al., 2016). It is important to incorporate the identified occupational heat stress risk concerns into national and workplace health and safety policies and adaptation strategies. Moreover, enforcing such policies promotes suitable job environments by reducing worker's vulnerability and enhancing their adaptive capacity and resilience to heat stress-related health and safety effects. It also enhances capacity of institutions working on climate-related health issues in low- and middle-income countries to prevent further health burdens in the context of climate change (Ebi and Otmani Del Barrio, 2017).

The outcome of the x^2 test for differences in the distribution of occupational heat stress risks experiences among background characteristics of the supervisory personnel is presented in Table 5. The disparities in the proportion of occupational heat stress risks experiences signified by workers concern about heat exposure ($x^2(1) = 0.000$,

Table 5
The difference in the distribution of occupational heat stress risks among background characteristics of supervisory personnel of mining workers (Chi-square test). Source: Authors, 2017.

Background characteristics	Experiences of occupational heat stress risks													
	Workers concern about heat exposure		Heat-related illness concerns		Experience of heat-related injury		Description of injury extent		Workers injury concerns		Witnessed any form of heat-related injury		Type of heat-related injury witnessed	
	n (%)	p-value	n (%)	p-value	n (%)	p-value	n (%)	p-value	n (%)	p-value	n (%)	p-value	n (%)	p-value
Type of mining:		1.000		0.980		1.000		1.000		0.634		1.000		0.419
SSM	7(43.8)		7(43.8)		7(43.8)		4(44.4)		4(44.4)		7(43.8)		7(43.8)	
LSM	9(56.2)		9(56.2)		9(56.2)		5(55.6)		5(55.6)		9(56.2)		9(56.2)	
Years of OHS work experience:		0.025*		0.013*		0.550		1.000		0.436		1.000		0.066
Under 10 years	3(18.8)		3(18.8)		3(18.8)		3(18.8)		3(18.8)		3(18.8)		3(18.8)	
10 years and over	13(81.2)		13(81.2)		13(81.2)		13(81.2)		13(81.2)		13(81.2)		13(81.2)	
Level of education:		0.475		0.175		0.060		0.524		0.094		0.302		0.225
Undergraduate	7(43.8)		7(43.8)		7(43.8)		6(66.7)		7(43.8)		7(43.8)		7(43.8)	
Graduate	9(56.2)		9(56.2)		9(56.2)		3(33.3)		9(56.2)		9(56.2)		9(56.2)	

p = 1.000), heat-related illness concerns ($x^2(4) = 0.429$, $p = 0.980$), experience of heat-related injury ($x^2(1) = 0.000$, $p = 1.000$), magnitude of heat-related injury ($x^2(2) = 0.000$, $p = 1.000$), worker's injury concerns ($x^2(2 = 0.912$, $p = 0.634$), heat-related injury ever witnessed ($x^2(1) = 0.000$, $p = 1.000$), and workers heat-related concerns witnessed ($x^2(2) = 1.740$, p = 0. 419) between categories of type of mining were not significant at 0.05 (Supplementary Tables 16–22). Also, the disparities in the distribution of occupational heat stress risks experiences characterised by workers concern about heat exposure ($x^2(1) = 0.327$, $p = 0.475$), heat-related illness concerns ($x^2(4) = 6.341$, $p = 0.174$), experience of heat-related injury ($x^2(1) = 2.520$, $p = 0.060$), magnitude of heat-related injury ($x^2(1) = 0.056$, $p = 0.524$), worker's injury concerns ($x^2(2) = 4.731$, $p = 0.094$), heat-related injury ever witnessed ($x^2(1) = 0.830$, $p = 0.302$), and workers heat-related concerns witnessed ($x^2(2) = 2.983$, $p = 0.225$) between categories of level of education were not significant at 0.05 (Supplementary Tables 23–29).

However, the disparities in the distribution of occupational heat stress risks experiences indicated by workers concern about heat exposure ($x^2(1) = 4.747$, $p = 0.025$) and heat-related illness concerns ($x^2(4) = 12.670$, $p = 0.013$) aside from the experience of heat-related injury ($x^2(1) = 0.059$, $p = 0.550$), magnitude of heat-related injury ($x^2(1) = 0.000$, $p = 1.000$), worker's injury concerns ($x^2(2) = 1.660$, $p = 0.436$), heat-related injury ever witnessed ($x^2(1) = 0.000$, $p = 1.000$), and workers heat-related concerns witnessed ($x^2(2) = 5.434$, $p = 0.066$) between categories of years of OHS work experience were significant at 0.05 (Supplementary Tables 30–36). Thus, whereas the differences in the distribution of occupational heat stress risks experiences between the categories (type of mines and level of education) were not significant, the differences in the distribution of occupational heat stress risks experiences based on workers' concern about heat exposure and heat-related illness concerns between the categories of years of OHS work experience were statistically significant at the level ($p < 0.05$).

3.4. Preventive and control measures of occupational heat stress due to climate change

Sustainable measures directed at avoiding and adjusting to the risks and worsening impacts of occupational heat stress due to climate change include, but are not limited to, the awareness and implementation of mitigation, adaptation and social protection strategies (Kjellstrom et al., 2016b; Nunfam et al., 2018). Significantly, all the respondents affirmed their awareness of the preventive and control measures of occupational heat stress due to climate change. As a result, drinking adequate water was identified by most (25.8%) of the respondents as a key measure for averting and adjusting to occupational heat stress. This was complemented by the use of air conditions and fans (22.6%), taking work breaks and resting in the shade (22.6%), and wearing loose and light-coloured clothing (7%) (Fig. 1).

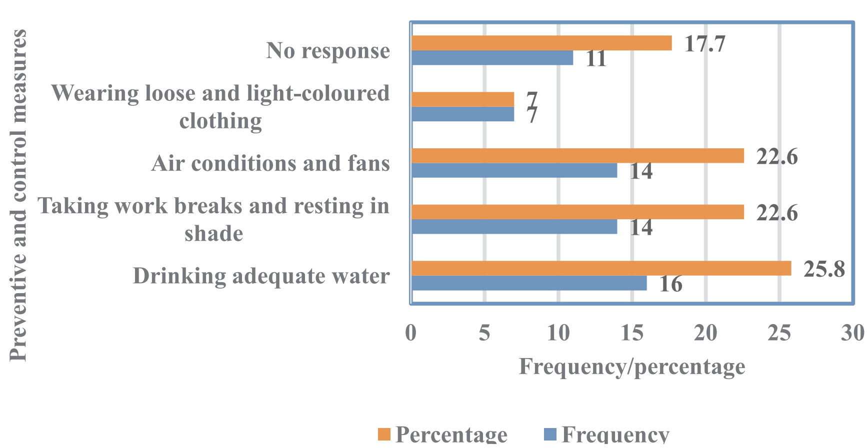

Fig. 1. Preventive and control measures of occupational heat stress due to climate change.
Source: Field survey, 2017.

Similarly, data from the in-depth interviews among the other stakeholders indicated the awareness and use of schedule work breaks and rest regimens, cooling systems, cold water, and structural designs to ensure airflow to prevent and control occupational heat stress among workers. Hence, the following extracts highlight the expressions of stakeholders during the interviews:

Yes. We also look at the temperatures where you [worker] are working. The surface temperature should not exceed 32.5 degrees, that is, the wet bulb. It should also not exceed 27 degrees, the wet bulb temperature in the mines underground. Where it exceeds 27 degrees, you have to make provisions for breaks and long resting time, so that they can take some water. All these happen in the underground environment. The wet bulb should not exceed 32.5 °C at all in the mine (KS3).

We have some breaks. Between 11.30 and 12.30 p.m. is when they take breaks for their lunch and have rest under shades. And in the offices, we have some fans and offices are built such that we have some tress and shelter around. They [workers] come to work at 7.30 a.m. have their breakfast, by 8.00 a.m. work resumes and between 11.30 a.m. and 12.30 p.m. they have their break and lunch, and by 4.30 p.m. we are done (KS2).

So this is where the occupational hygiene becomes very critical or fundamental. They design their own process if they will to allow more ventilation or more aeration in their offices, they design their structures to reflect that. If for one reason their structures do not have it and they have to put in an air condition they will do that. If for one reason they will have to supply a lot of tea for the workers or they have to provide more liquids, they will (KS1).

Findings from the survey and in-depth interviews as substantiated in analogous studies re-echoes the significance of workers' awareness and use of adaptation strategies (e.g., structural designs, cooling systems, drinking water, rest regimens, clothing type) in managing the risk and impact of occupational heat stress (e.g., Flocks et al., 2013; Lao et al., 2016; Pradhan et al., 2013). Aside from mitigation, the knowledge, awareness and enforcement of occupational heat stress adaptation strategies among cohorts of workplace managers and other stakeholders is substantial in improving and reinforcing policy decisions required in combating the effects of rising temperature and climate change (Stoecklin-Marois et al., 2013; Xiang et al., 2015b, 2016).

Table 6 shows results of the x^2 tests for difference in the distribution of perceived preventive and control measures of occupational heat stress due to climate change among background characteristics of supervisory personnel. There were more proportions of supervisory personnel within the SSM companies who identified taking work breaks and resting in shades (57.1%), as compared to more proportions of supervisory personnel within the LSM who identified wearing loose and light-coloured clothing (71.4%) as measures of preventing and controlling heat stress due to climate change among mining workers (Table 6). The difference in the distribution of preventive and control measures of heat stress due to climate change among mining workers within the type of mining was not significant ($x^2(2) = 1.221$, $p = 0.543$) (Supplementary Table 37).

Similarly, there were more proportions of supervisory personnel with undergraduate degrees who identified drinking adequate water (100%) and taking work breaks and resting in shade (57.1%) as compared to more supervisory personnel with graduate degrees who identified wearing loose and light-coloured clothing (85.7%) as measures of preventing and controlling heat stress due to climate change among mining workers. In this scenario, there was evidence that the difference in the distribution of preventive and control measures of heat stress due to climate change among mining workers within the level of education was significant ($x^2(2) = 6.628$, $p = 0.036$) (Supplementary Table 38).

In addition, there were more proportion of supervisory personnel with 10 years or more OHS work experience as compared to those with under 10 years who identified taking work breaks and resting in shades

Table 6
The difference in the distribution of perceptions of preventive and control measures of occupational heat stress due to climate change among background characteristics of supervisory personnel (Chi-square test).
Source: Authors, 2017.

Background characteristics	Preventive and control measures						Total	
	Drinking adequate water		Taking work breaks and resting in shades		Wearing loose and light-coloured clothing			
	n	%	n	%	n	%	n	%
Type of mining:								
SSM	1	50	4	57.1	2	28.6	7	43.8
LSM	1	50	3	42.9	5	71.4	8	56.2
Total	2	100	7	100	7	100	16	100
Level of education:								
Undergraduate	2	100	4	57.1	1	14.3	7	43.8
Graduate	0	0	3	42.9	6	85.7	8	56.2
Total	2	100	7	100	7	100	16	100
Years of OHS work experience:								
Under 10 years	1	50	0	0	2	28.6	3	18.8
10 years and over	1	50	7	100	5	71.4	13	81.2
Total	2	100	7	100	7	100	16	100

(100%) and wearing loose and light-coloured clothing (74.1%) as measures of preventing and controlling heat stress due to climate change among mining workers. But, the difference in the distribution of preventive and control measures of heat stress due to climate change among mining workers within the years of OHS work experience was not significant ($x^2(2) = 4.294$, $p = 0.117$) (Supplementary Table 39). Therefore, there is no evidence that the difference in the distribution of perceptions of preventive and control measures of occupational heat stress due to climate change among background characteristics, except the level of education of supervisory personnel was statistically significant at the level ($p < 0.05$).

4. Conclusions and implications for policy decisions

Work supervisors and other stakeholders are significant actors in the mining industry with the responsibility of directly supervising and regulating the activities of mining workers and companies in Ghana. This study provides insights into climate change and occupational heat stress risks and adaptation strategies of mining workers from the perspectives of their supervisors and other stakeholders, who play a vital role in leadership and policy to reduce risks and impacts on workers. Compared to other studies in developing regions (e.g., Asia, the Middle East, and Sub-Saharan Africa) (Pugliese and Ray, 2009), we found higher levels of climate change awareness and risk as reported in more developed countries. Although the supervisors and stakeholders were adequately aware of climate change risk and like other studies (e.g., Xiang et al., 2015b), their concern about workplace heat exposure due to climate change risk was moderate. The experiences of occupational heat stress risks of mining workers were associated with heat-related illnesses and minor injuries. Mining workers' awareness and use of adaptation strategies as observed by the supervisors and stakeholders included drinking adequate water, use of cooling systems, taking work breaks and rest, and wearing loose and light-coloured clothing.

Climate change risk perception and occupational heat stress risk experiences (based on workers' concern about heat exposure and heat-related illness) were associated with years of OHS work experience. Preventive and control measures of occupational heat stress due to climate change risk perception was associated with educational level. Educational attainment has been associated with climate change awareness as the single strongest predictor (Lee et al., 2015). The differences within years of OHS working experience and education level suggest that job experience and educational attainment are essential to any effective climate change risk perception and adaptation strategies to occupational heat stress due to climate change. An understanding of climate change risk perception, occupational heat stress risk experiences, and adaptation strategies of mining workers among supervisors and stakeholders are important for policymaking, risk communication and combating climate change impacts (Carlton and Jacobson, 2013; Lorenzoni and Pidgeon, 2006). It is also suitable for informing heat exposure education and training and heat stress management among mining workers to guarantee healthy lives, promote well-being, ensure decent jobs and work capacity. Consequently, this will help reduce vulnerability to the incidence of heat-related illness, injuries and possible death, and improve the adaptive capacity of mining workers.

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Declaration of interest

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Ethics

Ethical approval for the research was received from the Human Research Ethics Committee of ECU (Project Number 17487) prior to the commencement of the study

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envres.2018.11.004.

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