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Research article

Mixed methods study into social impacts of work-related heat stress on Ghanaian mining workers: A pragmatic research approach

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ABSTRACT

Although mixed methods research proves significant in understanding complex social phenomenon, inadequate research has explored its utility in heat exposure studies. The convergent mixed methods analysis comprising 320 surveys and two focus group interviews were used to evaluate the social impacts of occupational heat stress on Ghanaian mineworkers to enlighten policy choices for the purpose of complementarity. The study contributes to mixed methods study by affirming the practical use of between-method triangulation and complementarity. The merged quantitative and qualitative results also showed adequate corroboration and complementarity between both data, to illustrate the social impacts of work-related heat stress on mining workers as heat-related comorbidity, productive capacity loss, anxiety, slow pace of work, and inadequate social well-being. The mixed methods results would inform policy options on the health and safety of work settings, managing occupational heat stress, and adaptation guidelines in the mining industry.

1. Introduction

Globally, mixed methods research (MMR) have progressively become the third popular research methodological paradigm among researchers (Creswell, 2015; Greene, 2006; Johnson and Onwuegbuzie, 2004; Mertens, 2003; Tashakkori et al., 1998; Teddlie and Tashakkori, 2012). Unlike a quantitative or qualitative research strategy, MMR involves the process of gathering, assessing and mixing both qualitative and quantitative strategies, information and findings to enlighten inferences drawn from one or more studies to comprehensively understand a research phenomenon (Creswell, 2015; Creswell and Plano Clark, 2017; Plano Clark and Ivankova, 2016; Tashakkori & Teddlie, 2010, 2011). The basis of contemporary MMR emerged in the early 1950s with the introduction of the idea of triangulation and multiple operationalizm in social science research (Boring, 1953; Campbell and Fiske, 1959). However, MMR formally began in the late 1980s and developed throughout the second half of the 20th Century (Denzin, 1978; Greene et al., 1989; Sieber, 1973; Webb et al., 1999). The rationale for MMR is to adopt varied research philosophies, designs and sampling procedures, sources of data, approaches to data collection and analysis, integrate and discuss the results, and draw conclusions to offset the inadequacies of one research strategy (Creswell, 2015; Hesse-Biber, 2010).

Even though challenging, integration as the distinguishing feature of MMR involves the procedure of combining results of qualitative and quantitative studies. Three common strategies of integration are identified as connecting, building, and merging (Fetters et al., 2013). Connecting involves combining data by purposively selecting participants based on quantitative results for interviews while building is the systematic use of qualitative results of a study to apprise the design of a survey for another study. Merging is the combination of qualitative and quantitative data with the aim of comparison to seek whether the results based on the statistics and themes are different, compatible, or cross-tabulate. Integrated results of MMR may be presented using descriptive narrative or joint display to graphically enhance and characterize the combination (Fetters et al., 2013; Guetterman et al., 2015). However, integration may occur at various stages of the research process comprising multiple philosophies, paradigms, designs, and methods including sampling, data collection, analysis and interpretation (Fetters et al., 2013; Greene, 2015).

Notably, evidence of limited research articles characterized by MMR emanating from the developing world with reference to Africa compared to most articles from the developed countries exist. For instance, out of 685 peer-reviewed studies in journals of library and information science in sub-Saharan Africa, 53% employed quantitative methods, 40%

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adopted qualitative strategies, while 7% used mixed methods (Ngulube, 2010). Similarly, in content analysis, only 7% out of 322 articles published from 2003-2011 were identified to have MMR philosophies and designs within the South African Journal of Economics and Management Sciences (Ngulube and Ngulube, 2015). Furthermore, in a systematic analysis of 25 peer-reviewed studies based on the social impacts of work-related heat stress and workers' adaptation policies from 2007-2017, 76% were quantitative studies, 12% were qualitative studies, and 12% used mixed methods strategies (Nunfam et al., 2018). The inadequate proportions of articles associated with the use of MMR in Africa and studies related to social implications of work-related heat stress and adaptation approaches of workers may be due to integration and interpretation challenges of qualitative and quantitative data and findings related to research philosophical and design incompatibility thesis (Bryman, 2006; Denzin, 2008; Teye, 2012; Yanchar and Williams, 2006). Except for few recent articles on work-related heat stress published in content-specific journals illustrating the application of mixed methods (Dutta et al., 2015; Nunfam et al., 2019b; Nunfam et al., 2019c; Venugopal et al., 2016a, b) no empirical MMR related to occupation heat stress impacts on health and productivity as well as social well-being of workers have been published in mixed methods-specific journals. Given the methodological significance of MMR and the need to contribute to the extant growing literature on mixed methods and its utility, this empirical MMR paper seeks to apply the convergent mixed methods to assess the social impacts of work-related heat stress on mineworkers in Ghana to inform policy decisions with the intent of complementarity.

Work-related heat stress connotes heat stress condition induced by strenuous bodily work, increasing temperature and change in climate conditions or which is getting worsened because of exhaustive physical work, intensifying temperature and global climate change (Kjellstrom et al., 2016a). Work-related heat stress is induced by high workplace humidity and temperature conditions which hinder the body's normal thermoregulation response and leads to increases in core body temperature. When workers are under extreme heat exposure conditions, their body exceeds tolerable heat range (35–37 °C) and then loses its temperature regulatory capacity of sweating leading to a life-threatening condition (Crimmins et al., 2017; Parsons, 2014). Social impacts connote the physical or perceived consequence of a phenomenon on the culture, lives, cohesion, political arrangement, environment, health, fears and rights of people (Vanclay, 2003; Vanclay et al., 2015). Hence, social impacts of work-related heat stress comprise the safety, behavioral, health, mental, and societal well-being consequences due to heat stress on workers characterized by heat-related illness and injuries, mental and behavior concerns, and poor social well-being. Globally, indoor and outdoor workers in occupational settings (e.g., manufacturing, oil and gas, agricultural, mining, firefighting, military and construction) suffer higher risk and impact of excessive heat exposure. Work-related heat stress hazards and effects on employed populations susceptible to being exposed to heat conditions include, but are not limited to, physical safety and health concerns, socioeconomic effects, productivity and mental repercussions (Kjellstrom et al., 2016a; Nunfam et al., 2018; Venugopal et al., 2016a, b; Xiang et al., 2016). Significantly, the impacts of hazards associated with heat exposed workers in hot countries of tropical regions of the world characterized by low-and middle-income are much worse on account of intensifying global climate warming, inadequate resources, poor access to cooling systems, and the need to keep up with productivity and economic growth.

Following the last decade, research efforts in extant literature related to heat exposure studies in Africa, which have used either quantitative or qualitative methods, or both, to evaluate work-related heat stress have progressed (e.g., Frimpong et al., 2020; Frimpong et al., 2017; Ngwenya et al., 2018; Nunfam et al., 2020; Nunfam et al., 2021). However, except for studies (e.g., Miller, 2014; Nunfam et al., 2018; Venugopal et al., 2016a, b), not much interests have centered on studies linked to social impacts of work-related heat stress on various cohort of workers. Also, no mixed methods empirical studies are conducted on social impacts of work-related heat stress on workers in the context of the African region, especially among Ghanaian mineworkers. Therefore, it is imperative to satisfy this need in literature by employing the convergent mixed methods paradigm to assess the social impacts of occupational heat stress on Ghanaian mineworkers with the prospects of stimulating more interest in workplace heat exposure studies in Africa. This will also support and widen the scope of using varied research approaches to measure workers' perceptions of occupational heat stress impacts on their healthiness, productivity, and psychosocial well-being. Considering the inadequae use of mixed methods approach to assess the social impacts of occupational heat stress on workers, the question which remains unanswered is, what is the extent of social impacts of occupational heat stress on small- and large-scale Ghanaian mining workers? Thus, the justification and relevance of this research is its potental to provide comprehensive understanding on the social impacts of occupation heat stress on mining workers which could have practical implications for heat exposure studies, occupational heat stress appraisal programs, and occupational health and safety assessment to enlighten policy options.

2. Theoretical perspective for MMR

Conceptual and theoretical philosophies that undergird the rationale of MMR include triangulation, complementarity, initiation, development and expansion (Bryman, 2006; Hesse-Biber, 2010). The concept of triangulation (within-method or between-methods) involves the combination of multiple data, theories, methodologies and researchers to study similar phenomenon for convergence and corroboration of results based on varied methods (quantitative and qualitative approach) (Denzin, 1978; Greene et al., 1989). Complementarity comprises multiple approaches used to measure the overlapping and varied aspects of a research problem and to complement the inadequacies inherent in the findings of a single method study, and thus, clarify, elaborate, boost and illustrate a holistic understanding of the research phenomenon (Greene et al., 1989; Hesse-Biber, 2010). Initiation is the process of starting a new study based on contradictory findings of a previous study, which requires further clarification. The purpose of initiation is to discover contradictions, new contextual viewpoints, reframe findings or questions of one technique with findings or questions of another technique (Greene et al., 1989; Hesse-Biber, 2010). Development connotes the process by which the findings of one method is used to enlighten another method (Greene et al., 1989). Expansion involves increasing the scope of a research inquiry based on the use of varied methods for different aspects of the research problem (Greene et al., 1989; Hesse-Biber, 2010).

Between-method triangulation and complementarity served as the basis for employing a convergent mixed method in this research. Hence, this study used multiple research designs, data, and methods in complementary and corroborative way to assess the social impacts of work-related heat stress on Ghanaian mining workers and to provide answers in response to the following research objectives: (1) To understand the perceptions and experiences of the social impacts of occupational heat stress on mining workers (Qualitative objective). (2) To assess the supposition that there is no significant variation in social impacts of occupational heat stress on mining workers between the type of mining activity (Quantitative objective). The independent and yet connected nature of the specific objectives support the use of convergent parallel design which requires the combination of quantitative and qualitative strategies, analyzing and merging the findings for a thorough and richer discussion and interpretation regarding the social impacts of work-related heat stress on mining workers.

3. Materials and methods

3.1. Research philosophy and design

This study was guided by the pragmatist methodological research perspectives which support mixed methods approach to a social inquiry

(Biesta, 2010; Johnson and Onwuegbuzie, 2004; Teddlie and Tashakkori, 2012). Pragmatism underscores an eclectic blend of both quantitative and qualitative ideas of positivism and interpretive theories to specify a broad understanding of the problem being researched (Creswell, 2013; Sarantakos, 2012). Consistent with pragmatists' research ideas, the convergent mixed methods research design involving quantitative (e.g., survey research) and qualitative (e.g., interpretive phenomenological research) strategies were employed to assess the problem being studied (Creswell, 2013; Creswell and Plano Clark, 2017). Both qualitative and quantitative research approaches were combined for the purpose of between-methods triangulation and complementarity of multiple philosophical paradigms, research designs, data gathering and analysis methods to gain a comprehensive understanding of the occupational heat stress impacts on Ghanaian mining workers (Denzin, 1978; Greene et al., 1989; Hesse-Biber, 2010). The essence of triangulation is to seek convergence and validation of results of both strategies, while complementarity is to use quantitative and qualitative methods to measure distinct but overlapping aspects of the social impacts of work-related heat stress on mining workers (Creswell, 2013; Mertens, 2015). Figure 1 illustrates the steps involved in the convergent mixed methods design of this research.

MMR designs have shown to be valuable in evaluating concerns based on change in global climate and heat stress impacts and adaptation which involve multiple interrelating systems characterized by socio-economic, health, and institutional implications for which the extent of knowledge ought to be assessed (Birchall et al., 2016; Mertens, 2015). For instance, the mixed method research design was used in studying climate change adaptation in Zimbabwe by triangulating qualitative and quantitative data for complementarity. The study also used simple random and purposive sampling in selecting respondents while survey questionnaires, interview guide, FGDs guide and observation were employed in data collection (Tanyanyiwa and Kanyepi, 2015). Similarly, the mixed methods approach involving the use of three exclusive sets of data (e.g., qualitative in-depth interviews, quantitative surveys and quantifiable documents) were employed in researching the voluntary carbon market in New Zealand. The study also used explanatory (qualitative interviews and survey findings) methods together with convergent (sets of data examined distinctly and combined for analysis) techniques in data collection and analysis (Birchall et al., 2016).

The use of qualitative approach is to offer the needed strategy to gain a detailed understanding of an in-depth context of mining workers' experiences and perceptions of the social impacts of work-related heat stress on mineworkers. It is also to promote some degree of flexibility in data collection and analysis, avoid pre-determined assumption while focusing on meanings of important variations of participants' perspectives of the study. However, qualitative research approach can be bias, time-consuming, expensive, and relies on small participants whose results cannot be generalized. In using the quantitative approach, the study sought to analysis and explain the differences and/or relationships among respondents' demographic characteristics and to offer a comprehensive understanding of the mining workers' view of the social impacts of occupational heat stress. This approach is relatively objective, less costly and time-consuming, uses large samples whose results can be generalized, but is limited in providing detailed perspectives of participants. Mixed methods design tends to allow complementarity in strength and weaknesses between qualitative and quantitative strategies of research as compared to a single method strategy. Thus, the use of mixed methods in this study offered the opportunity to accentuate respondents' experiences and/or differences in social impacts of occupational heat stress on mining workers. This holistic understanding of the social impacts of work-related heat stress may not be possible with a single method (quantitative or qualitative) study.

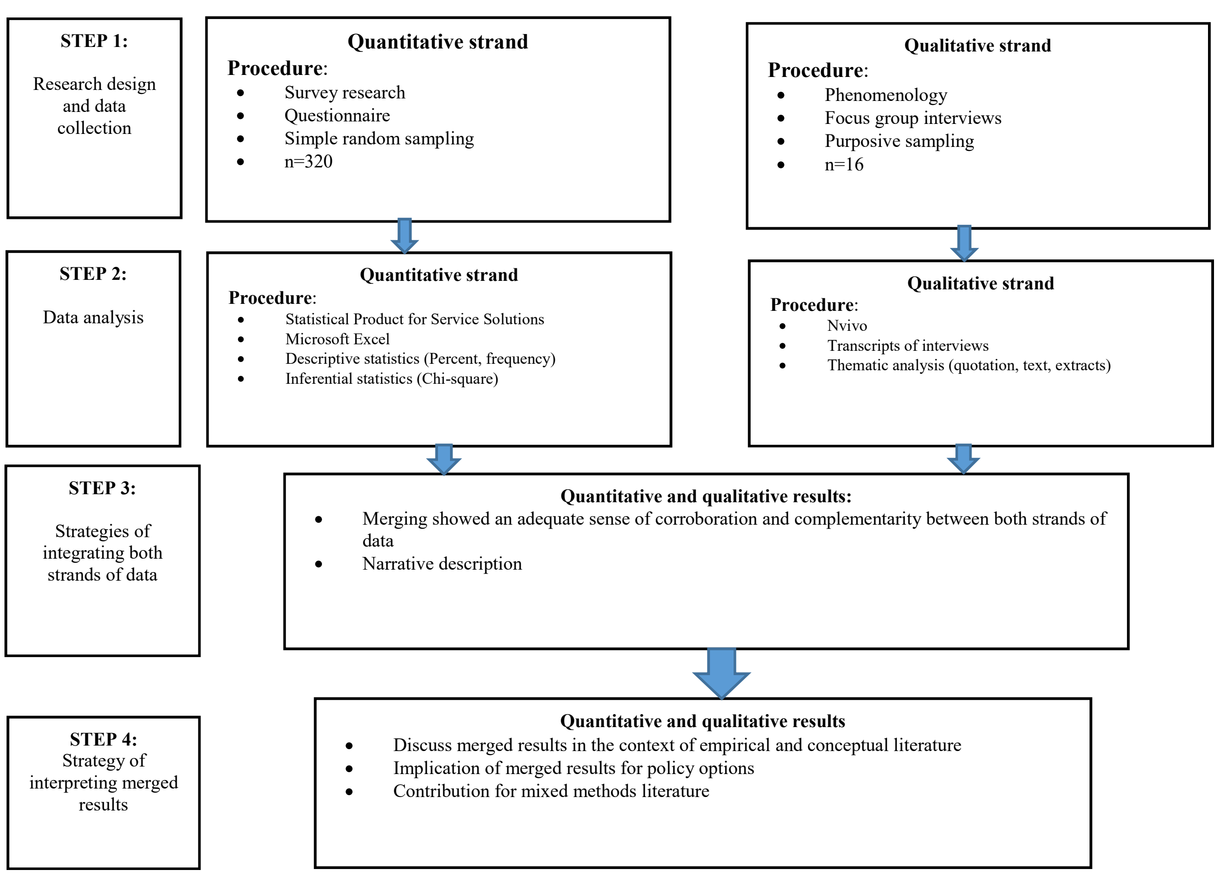

Figure 1. An illustration of steps involved in the convergent mixed methods design of this study. Source: Adapted from Creswell and Plano Clark (2017).

3.2. Study setting, population, sampling procedure and sample size

This study was carried out in Ghana located in the West African sub-region. Ghana is associated with a tropical weather condition, intensifying temperature and risk of heat exposure, inadequate technological advancement and lower adaptive capacity due to barriers to heat stress adaptation strategies (Nunfam et al., 2020). The climate conditions in Ghana put outdoor workers in its mining industry, particularly in the informal and small-scale mining (SSM) as well as the large-scale mining (LSM) sectors in danger of occupational heat stress. SSM sector comprises local people with inadequate finance and technology who employ labor-exhausting techniques and simple equipment to semi-mechanized mining equipment in their mining activities while LSM sector is dominated by multinationals with adequate funding who use advanced technology and expertise in their mining operations (McQuilken and Hilson, 2016). The study involved workers of five mining locations within the

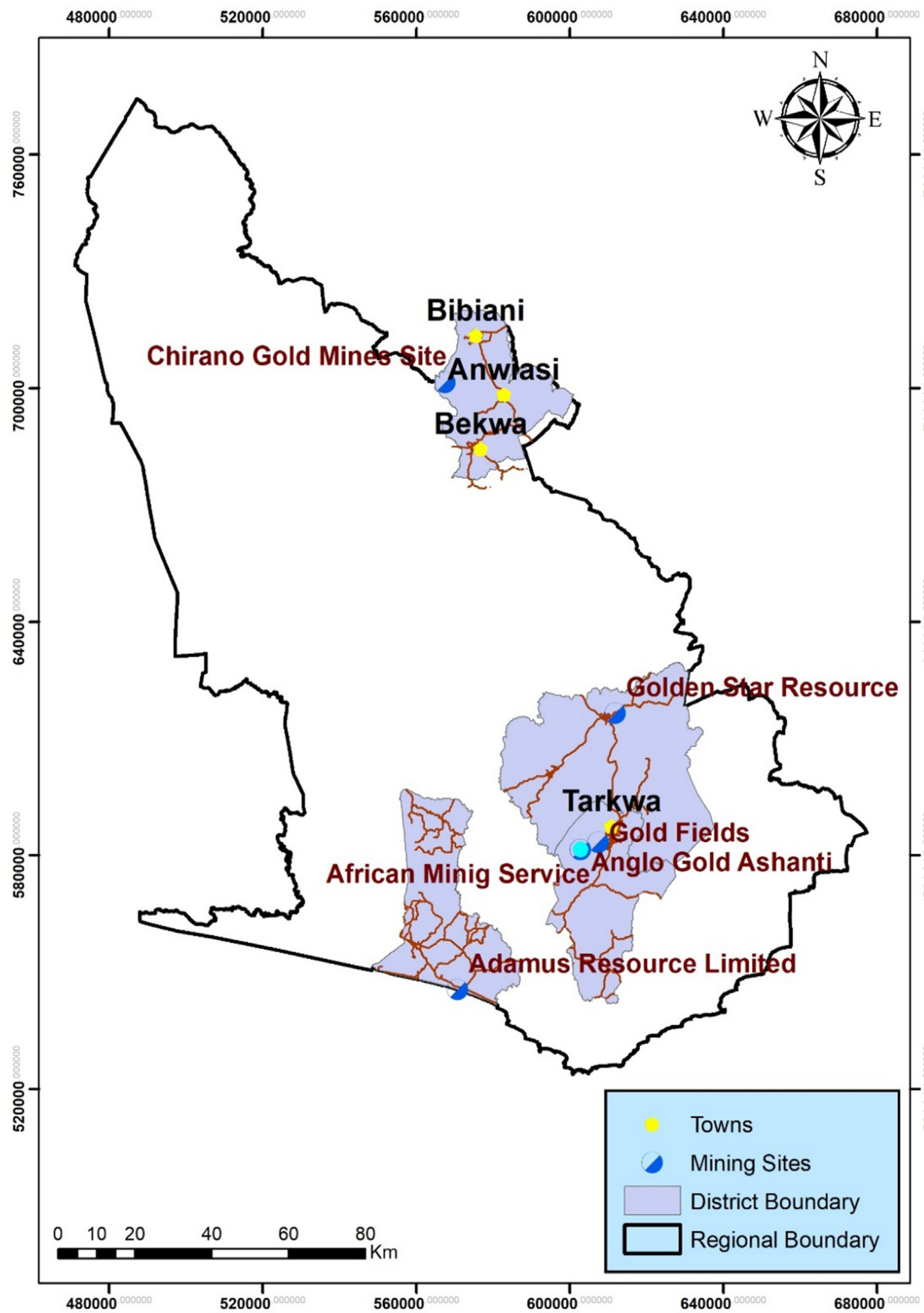

Figure 2. A map illustrating five mining sites situated in the Western Region of Ghana. Source: Reprinted by permission from Springer Nature, International Journal of Biometeorology, Barriers to occupational heat stress risk adaptation of mining workers in Ghana (Nunfam et al., 2020a).

previous Western Region (currently delineated as the Western North and Western Region) of Ghana, which is famous for the activities of SSM and LSM companies (Figure 2).

Over a million mine workers constituted the study population and comprised an estimated population of a million workers in the small-scale mining sectors (McQuilken and Hilson, 2016) and 11,628 workers from 13 mining corporations in the large-scale mining sector as of 2017 (Ghana Chamber of Mines (GCM), 2018). In cognizance of the over 1,000,000 mining workers, a sample size (384) participants was defined for the study (Krejcie and Morgan, 1970). In recruiting the participants, eight out of an estimated 177 SSM companies and five from 13 LSM companies willing and interested in the study were purposively selected. Subsequently, a sample size of 320 workers comprising 161 SSM and 159 LSM who showed interest and stated their willingness and consent to partake in the study were selected by employing the simple random sampling procedure. During the recruitment process of the survey, purposive sampling was also used to select 16 mining workers who consented and willingly participated in two focused group discussions (FGDs) consisting of eight members each for the category of SSM (FGD 1) and LSM (FGD 2) workers. Based on the eligibility criteria, participants were included in the survey, if they had basic knowledge of speaking, reading, and writing of the English Language, were an adult (above18 years) who have working experience with licensed mining operations for not less than a year. On the other hand, participants were excluded if they were persons under the legal employable age (18 years) and employees of an unlicensed mining business as well as workers of mining companies not extracting gold. Consequently, a response rate (83.3%) based on retrieving 320 validly completed questionnaires out of the 384 questionnaires distributed to the participants was recorded.

3.3. Data collection

This study relied on primary data collected as part of a doctoral thesis that assessed climate change, work-related heat stress and adaptation policies of Ghanaian mining workers to illustrate convergent mixed methods inquiry. The self-administered questionnaire which was filled by the respondents themselves was employed to gather quantitative data from the mineworkers. Though self-reported data is associated with possible weaknesses of common methods bias, non-response and errors of measurement (Podsakoff et al., 2012; Tehseen et al., 2017), it often permits the usage of multiple items which provide the opportunity to directly gauge heat exposure impacts as a multi-layered latent construct (Maula and Stam, 2019). The self-reported questionnaire comprised 33 question items including Likert-scales in two sections. Section one (25 Likert-scales items) entailed measures across four constructs including work-related heat stress effects on health and safety (7 items), productivity (5 items), behaviour (5 items), and social well-being (8 items). A closed-ended 5-point Likert scale extending from Strongly Disagree (1) to Strongly Agree (5) was used to rate the items. Section two included measures of participants' demographics (e.g., age, gender, and education) (3 items) and work characteristics (e.g., working hours, workplace environment, job physicality, work around heat sources and workload) (5 items) (Nunfam, 2019). The design and content of the survey questionnaire was guided and informed by the validated instruments of High Occupational Temperature Health and Productivity Suppression (HOT-HAPS) program as well as previous empirical studies based on impacts of climate change and heat exposure on workers' healthiness, productivity and adaptation guidelines (Kjellstrom et al., 2009a; Xiang et al., 2015). The self-reported question items centered on respondents' demographic and work characteristics, health and safety concerns, behavioral and psychological effects, productivity issues and societal well-being concerns of occupational thermal stress on mining workers. The guided FGD consisted of open-ended question items and were centered on participants' demographic and work characteristics, work-related heat stress effects on workers' safety, healthiness, behavior, psychology, productivity and societal well-being. The questionnaire and guided FGD were revised by experts in Edith Cowan University (ECU) and approved by ECU's Human Research Ethics Committee (HREC) with Project Number 17487 on 16/08/2017. Prior to the fieldwork (October 2017 to December 2017), the revised instruments were subjected to further peer review to ensure its content was valid and concise, suitable words were used, survey bias and possible ambiguities were reduced. Additional practical remedies as reminding participants of confidentiality, privacy and anonymity of response as well as motivating participants' to answer question items with honesty aided in decreasing common methods bias (Nunfam et al., 2021; Podsakoff et al., 2012). Pretesting of the questionnaire among eligible mining workers for the study in the Central Region other than same mining workers of the sudy in the Western Region of Ghana also led to further but minor variations to some items with low internal reliability (Nunfam, 2019; Nunfam et al., 2021).

3.4. Data analysis

IBM Statistical Product and Service Solution (SPSS) version 25 and Microsoft Excel 2016 were employed in data processing. Descriptive statistical techniques involving frequency and percent, and inferential statistical methods based on Chi-Square test were used to establish the variation in social impacts of work-related heat stress on mining workers between the type of mining activity at a significance level ($p < .05$). Also, the degree of significant difference was determined by the effect size criteria, namely, very small (0.01), small (0.20), medium (0.50), large (0.80), very large (1.20), and huge (2.0) (Cohen, 1988; Sawilowsky, 2009). The recorded and transcribed qualitative data were reviewed, validated and process with the help of Nvivo version 11. The data on workers' insights and experiences of social impacts of work-related heat stress was then thematically analyzed and synthesized into themes that emerged from the texts, quotes and excerpt of the FGDs. The themes assisted in describing and interpreting the data based on the relationships and differences arising from the social impacts of work-related heat stress on mineworkers. Based on the convergent mixed methods strategy, I integrated by merging and narratively described the quantitative (e.g., *statistics*) and qualitative (e.g., *themes*) results simultaneously to facilitate

Table 1. Variations in type of mining activity amongst workers' demographic factors.

Type of mining activity	Demographic factors					
	Sex		Age		Education	
	Male	Female	Younger (21–49yrs)	Older (50–61yrs)	No formal education	Formal education
	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)
SSM	144(89.4)	17(10.6)	151(93.8)	10(6.2)	9(5.6)	152(94.4)
LSM	115(72.3)	44(27.7)	144(90.6)	15(9.4)	0(0)	159(100)
Total	259(80.9)	61(19.1)	295(92.2)	25(7.8)	9(2.8)	311(97.2)
	$\chi^2(1) = 15.186$, $p < .001$, $Phi = 0.218$		$\chi^2(1) = 1.154$, $p = 0.283$		$\chi^2(1) = 9.145$, $p < .001$, $Phi = 0.169$	

NB: SSM = Small scale mining; LSM = Large scale mining; n = 320; n (SSM) = 161; n (LSM) = 159.
Source: Field survey, 2017

Table 2. Variations in type of mining activity amongst workers' occupational factors.

Type of mining activity	Occupational factors										
	Work hours		Work environment		Work effort		Work around heat source		Workload		
	Under 10hrs/day	Over 10hrs/day	Indoor	Outdoor	Less	More	Yes	No	Light	Moderate	Heavy
	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)
SSM	84(52.2)	77(47.8)	94(58.4)	67(41.6)	12(7.5)	149(92.5)	149(92.5)	12(7.5)	8(5.0)	39(24.2)	114(70.8)
LSM	29(18.2)	130(81.8)	117(73.6)	42(26.4)	48(30.2)	111(69.8)	130(81.8)	29(18.2)	13(8.2)	59(37.1)	87(54.8)
Total	113(35.3)	207(64.7)	211(65.9)	109(34.1)	60(18.8)	260(81.3)	279(87.2)	419(12.8)	21(6.6)	98(30.6)	201(62.8)
	$\chi^2(1) = 40.329, p < .001, Phi = 0.355$		$\chi^2(1) = 8.229, p < .05, Phi = -0.160$		$\chi^2(1) = 27.142, p < .001, Phi = -0.291$		$\chi^2(1) = 8.331, p < 0.05, Phi = 0.161$		$\chi^2(3) = 38.936, p < .001, V = -0.349$		

NB: n = 320; n (SSM) = 161; n (LSM) = 159.
Source: Field survey, 2017

interpretation and discussion, conclusions and implications (Fetters and Freshwater, 2015; Fetters and Molina-Azorin, 2019). Weaving, as a dynamic approach to narrative integration, was then used to present results theme-by-theme consisting of both the quantitative and qualitative data (Fetters and Freshwater, 2015). Tables and figures were also used to illustrate the results of the study where necessary.

4. Results

Results of the quantitative analysis were illustrated with descriptive and inferential statistics and supplemented with comparable data from the qualitative findings, which produced four key themes (health and safety concerns, behavioral and psychological effect, productivity issues, and social well-being concerns).

4.1. Descriptive summary of respondents' background information

The composition of gender showed that there were 80.9% males (SSM: 89.4% vs LSM: 72.3%), and 19.1% females (SSM: 10.6% vs LSM: 27.7%) and the variation in gender composition between the type of mining activity was statistically significant ($p < .001$) by small effect size. Also, the age categorization comprised 92.2% younger respondents (SSM: 93.8% vs LSM: 90.6%), and 7.8% older respondents (SSM: 6.2% vs LSM: 9.4%) and the disparity in age category among workers of SSM and LSM was not statistically significant. Similarly, respondents (2.8%) without formal education consisted of SSM (5.6%) and LSM (0%) workers while those with formal education composed of workers of SSM (94.4%) and LSM (100%). The disparity in education level between the type of mining activity was statistically significant ($p < .001$) by a very small effect size (Table 1).

Also, the work hours category showed that there were 35.3% respondents working under 10hrs/day (SSM: 52.2%% vs LSM: 18.8%) and 64.7% respondents working over 10hrs/day (SSM: 47.8% vs LSM: 81.8%). The distinction in work hours between the type of mining activity was statistically significant ($p < .001$) by a small effect size. Also, based on the work environment category, there were 65.9% indoor workers (SSM: 58.4% vs LSM: 73.6%) and 34.1% outdoor workers (SSM: 41.6% vs LSM: 26.45). The dissimilarity in the work environment among workers of SSM and LSM was statistically significant ($p < .001$) by a very small effect size. In terms of work efforts, respondents (18.8%) with less work effort comprised 7.5% and 30.2% workers of SSM and LSM respectively, and the respondents (81.3%) with more work effort composed of SSM (92.5%) and LSM (69.8%) workers. The difference in work effort between the type of mining activity was statistically significant ($p < .001$) by a small effect size. Furthermore, respondents (87.2%) who answered in the affirmative to working close to heat sources consisted of workers of SSM (92.5%) and LSM (81.8%). However, the respondents (12.8%) who answered negatively comprised SSM (7.5%) and LSM (18.2%) workers. The discrepancy in working close to sources of heat across workers of SSM and LSM was statistically significant ($p < .05$) by a very small effect size. Lastly, the 6.6% participants with light workload comprised 5.0% SSM and 8.2% LSM workers, moderate workload (30.6%) included SSM (24.2%) and LSM (37.1%) workers, and heavy workload (62.8%) consisted of 70.8% SSM and 54.8% LSM workers. The variation in workload between the type of mining activity was statistically significant ($p < .001$) by a small effect size (Table 2).

4.2. Health and safety concerns

Concerns related to heat stress effects on workers' health and safety emerged from the views of mining workers contained in both the quantitative and qualitative data. The workers were conscious that workplace heat exposure constitute a significant danger to their health and safety, as shown by the quantitative data. For instance, the majority of workers (SSM and LSM) agreed that intensive physical mining labor in hot weather environments resulted in excessive sweating,

Table 3. Variations in health and safety effects of work-related heat stress on mining workers amongst the type of mining activity.

Statement	SA		A		U		D		SD		Chi-square
	SSM	LSM	SSM	LSM	SSM	LSM	SSM	LSM	SSM	LSM	
	%	%	%	%	%	%	%	%	%	%	
Intensive physical mining work in hot weather conditions results in excessive sweating, headaches, and dizziness	84.5	83.0	12.4	15.7	1.2	0.6	1.9	0.0	0.0	0.6	$\chi^2(4) = 4.936$, $p = .294$
Doing mining work in hot weather conditions increases the risks of tiredness, weakness, and muscles cramps or body pains	72.0	70.4	23.6	25.8	1.2	2.5	2.5	0.0	0.6	1.3	$\chi^2(4) = 5.172$, $p = .270$
Excessive sweating as a result hot weather conditions during intensive mining work enhances the potential for heat rashes	75.8	45.9	11.8	33.3	6.2	0.6	1.9	19.5	4.3	0.6	$\chi^2(4) = 63.281$, $p < .001$, $V = 0.445$
Excessive sweating due to heat exposure increases the risk of extreme thirst	83.2	72.3	13.0	25.8	2.5	1.3	0.6	0.6	0.6	0.0	$\chi^2(4) = 9.556$, $p < .05$, $V = .173$
Intensive work in hot weather conditions enhance the risk of injuries such as heat burns from the sun or hot surfaces	37.9	44.0	52.8	45.3	3.1	5.7	5.6	3.8	0.6	1.3	$\chi^2(4) = 3.759$, $p = .440$
Fatigue, confusion and lack of concentration due to heat exposure during heavy mining work leads to heat-related injuries likes skin burns, bruises and cuts	29.2	47.8	62.1	44.0	1.9	4.4	2.5	2.5	4.3	1.3	$\chi^2(4) = 16.497$, $p < .05$, $V = 0.227$
Loss of grip and control of mining equipment due to sweaty hands results in heat-related injuries like skin burns, bruises, and cuts	28.6	42.1	24.2	49.1	36.0	3.1	5.0	3.1	6.2	2.6	$\chi^2(4) = 64.744$, $p < .001$, $V = 0.450$

NB: n = 320; n (SSM) = 161; n (LSM) = 159.
Source: Field survey, 2017

headaches and dizziness (over 98%), doing mining work in hot climate settings increased the risks of tiredness, weakness, and muscle cramps or body pains (>95%), excessive sweating as a result of hot weather conditions during intensive mining work enhanced the potential for heat rashes (>79.2%), excessive sweating due to heat exposure increased the risk of extreme thirst (over 98%) (Table 3). However, the results showed statistically significant variation across SSM and LSM workers as to whether excessive sweating as a result of hot weather conditions during intensive mining work enhanced the potential for heat rashes ($p < .001$), and excessive sweating due to heat exposure increased the risk of extreme thirst ($p < .001$) (Table 3). In addition, most discussants supported and complemented the results of the quantitative data based on their perceptions and experiences of heat-related morbidity connected with mining work. This was confirmed by participants during the FGDs as depicted by one of the LSM workers in this extract:

> *I experienced illness while working in places where there is heat or more heat, and you need to do that job. You need to be as fast as you can to do that job by not risking yourself, but at the end of the work you will find yourself feeling dehydrated, you are sweating and have a little bit of headache…most of our friends also get these heat illness like sweating and collapsing too.*

Similarly, the majority of workers affirmed that intensive work in hot weather conditions enhanced the risk of injuries such as heat burns from the sun or hot surfaces (>85%), fatigue, confusion and lack of concentration due to heat exposure during mining work led to heat-related injuries like skin burns, bruises and cuts (over 91%), and loss of grip and control of mining equipment due to sweaty hands resulted in heat-related injuries like skin burns, bruises and cuts (over 52%). Evidence of statistically significant disparity between SSM and LSM workers was found regarding the statements that fatigue, confusion and lack of concentration due to heat exposure during mining work led to heat-related injuries like skin burns, bruises and cuts ($p < .001$) and loss of grip and control of mining equipment due to sweaty hands resulted in heat-related injuries like skin burns, bruises and cuts ($p < .001$) (Table 3). Comparable sentiments were articulated by SSM participants involved in the FGD to illustrate their perceptions and experiences linked to heat stress effects on their health and safety. This is exemplified in the following statement by an SSM worker:

Table 4. Variations in behavioural and psychological effects of work-related heat stress on mining workers amongst the type of mining activity.

Statement	SA		A		U		D		SD		Chi-square
	SSM	LSM	SSM	LSM	SSM	LSM	SSM	LSM	SSM	LSM	
	%	%	%	%	%	%	%	%	%	%	
Tiredness, weakness and muscle cramps due to high temperature slow down the pace of mining workers	37.3	46.5	15.5	45.9	37.9	0.6	8.7	6.3	0.6	0.6	$\chi^2(4) = 83.695$, $p < .001$, $V = 0.511$
Physical fatigue and excessive sweating due to heat exposure affects the attentiveness and judgement of mining workers	63.4	50.3	22.4	40.3	1.2	0.6	10.6	7.5	2.5	1.3	$\chi^2(4) = 12.485$, $p < .05$, $V = .196$
Thoughts of risk of accidents and injuries due to heat-related exhaustion reduced alertness and sense of understanding increase the fear and anxiety of mining workers	21.1	49.7	58.4	29.6	6.2	6.9	10.6	12.6	3.7	1.3	$\chi^2(4) = 35.867$, $p < .001$, $V = 0.335$
Fatigue, weakness and lack of concentration due to intensive mining work in hot environment increase the need for work-rest hours for mine workers	30.4	60.4	60.9	33.3	3.1	2.5	5.0	3.8	0.6	0.0	$\chi^2(4) = 30.031$, $p < .001$, $V = 0.306$
Mistakes/errors during work in hot weather conditions are due to lack of training and information on risk of heat exposure	64.0	56.6	19.3	19.5	1.9	3.1	12.4	17.6	2.5	3.1	$\chi^2(4) = 2.808$, $p = .591$

NB: n = 320; n (SSM) = 161; n (LSM) = 159.
Source: Field survey, 2017

Table 5. Variations in productivity effects of work-related heat stress on mining workers amongst the type of mining activity.

Statement	SA		A		U		D		SD		Chi-square
	SSM	LSM	SSM	LSM	SSM	LSM	SSM	LSM	SSM	LSM	
	%	%	%	%	%	%	%	%	%	%	
Tiredness, weakness and muscle cramps due to intensive mining work in hot environment reduces productive capacity of mining workers	72.7	44.0	16.1	47.8	1.2	0.0	8.1	7.5	1.9	0.6	$\chi^2(4) = 39.352, p < .001, V = 0.351$
Lack of concentration, confusion and coordination as result of heat exposure leads to loss of productive efficiency of mining workers	67.7	40.9	15.5	50.3	3.1	1.9	13.7	6.3	0.0	0.6	$\chi^2(4) = 45.925, p < .001, V = 0.375$
Heat-related illness and injuries increase the risk of absenteeism of mining workers	32.3	42.1	55.9	44.7	2.5	1.9	8.7	8.8	0.6	2.5	$\chi^2(4) = 6.064, p = .195$
Absenteeism of mining workers due to heat-related illness and injuries result in loss of income and employment opportunities	29.2	44.0	56.5	39.7	3.7	3.1	9.9	11.3	0.7	1.9	$\chi^2(4) = 10.809, p < .05, V = 0.184$
Work-rest regimes due to excessive heat exposure increase the risk of reducing productivity of mining workers	21.1	34.6	61.5	50.9	4.3	1.3	11.2	11.3	1.9	1.9	$\chi^2(4) = 9.521, p < .05, V = 0.172$

NB: n = 320; n (SSM) = 161; n (LSM) = 159.
Source: Field survey, 2017

> *With small-scale mining, illness or injury is inevitable. It is common with our work in the underground…, at times your leg will hit a stone or a rock, and you will get hurt. I got hurt both my leg and hands. It is only God that protects us from our work. Sickness is always there because of the heat and hot air that we breathe. For sickness like headache, it is always there if you work so hard carrying a heavy load on your head.*

4.3. Behavioral and psychological effect

Mining workers' actions, emotions, mental state and attitude were influenced by their exposure to workplace heat consequences. As evident in the quantitative data, the majority answered in the affirmative that tiredness, weakness and muscle cramps due to high temperature slowed down the pace of mining workers (over 52%), physical fatigue and excessive sweating due to heat exposure affected the attentiveness and judgement of mining workers (>85%), thoughts of risk of accidents and injuries due to heat-related exhaustion reduced alertness and sense of understanding increased the fear and anxiety of mining workers (>79%), fatigue, weakness and lack of concentration due to intensive mining work in hot environment increased the need for work-rest hours for mine workers (over 91%), and mistakes/errors during work in hot weather conditions were occasioned by lack of training and information on risk of heat exposure (>76%) (Table 4). The stories of workers' perceptions and experiences during the FGDs showed that mining workers' actions and expressions of feelings and anxieties were based on work-related heat stress effects, as indicated in the following narratives:

> *I will add that sometimes when you are working in the sun or heat conditions; you shouldn't rush...work slowly because sometimes when you rush and do the work, you will start sweating or become tired early and may make mistakes or injure your body (Participant, LSM workers).*

> *I agree with you. Working under a hot environment will surely affect your behavior because you get distressed and become worried when the heat affects you. In any matter, you need the patience to resolve it, but you may not have that patience because you are feeling hot and irritated. You can even give an undeserving answer to someone that you are working with, which may not be a good behavior* (Participant, SSM workers).

The difference in the behavioral and psychological effect of work-related heat stress on workers between the type of mining activity was assessed using Chi-square. There was indication of statistically significant variation across SSM and LSM workers as to whether tiredness, weakness and muscle cramps due to high temperature slowed down the pace of mining workers ($p < .001$), physical fatigue and excessive sweating due to heat exposure affected the attentiveness and judgement of mining workers ($p < .001$), thoughts of risk of accidents and injuries due to heat-related exhaustion reduced alertness and sense of understanding increased the fear and anxiety of mining workers ($p < .001$), and fatigue, weakness and lack of concentration due to intensive mining work in hot environment increased the need for work-rest hours for mine workers ($p < .001$) (Table 4).

4.4. Productivity issues

Workers' productive capacity, effective performance and output were affected by work-related heat stress. The quantitative findings indicated majority of workers (SSM and LSM) were of the view that tiredness, weakness and muscle cramps due to intensive mining work in hot environment reduced the productive capacity of mining workers (over 88%), lack of concentration, confusion and coordination as a result of heat exposure led to loss of productive efficiency of mining workers (over 83%), heat-related illness and injuries increased the risk of absenteeism of mining worker (>86%), absenteeism of mining workers due to heat-related illness and injuries resulted in loss of income and employment opportunities (above 83%), and work-rest regimes due to excessive heat exposure increased the risk of reducing the productivity of mining workers (>82%) (Table 5). Nonetheless, the difference between SSM and LSM was statistically significant in whether tiredness, weakness and muscle cramps due to intensive mining work in hot environment reduced the productive capacity of mining workers ($p < .001$), lack of concentration, confusion and coordination as a result of heat exposure led to loss of productive efficiency of mining workers ($p < .001$), absenteeism of mining workers due to heat-related illness and injuries resulted in loss of income and employment opportunities ($p < .05$), and work-rest regimes due to excessive heat exposure increased the risk of reducing productivity of mining workers ($p < .05$) (Table 5). Like the quantitative data, the results of the FGDs with participants also indicated that mining work in hot environment resulted in exhaustion, slow work pace, and lack of concentration as well as the loss of productive capacity, low energy, and absenteeism which affects productivity and effective performance. This is apparent in the quotations from both SSM and LSM workers in the FGDs as follows:

> *With regard to mining work, it is hard and tiresome, so when you get tired you are not able to concentrate on anything again…when they bring the load and am tired, I cannot work effectively. Sometimes my work rate is slow, and my boss becomes annoyed or when l cannot continue to work again as I'm tired* (Participant, SSM workers).

> *Yes, because we have targets that we set in the mines and if the work that I'm doing exposes me to the heat. Definitely, I'm a human being and not a machine; even machine when it works above the normal temperature the*

Table 6. Variations in social well-being effects of work-related heat stress on mining workers amongst the type of mining activity.

Statement	SA		A		U		D		SD		Chi-Square
	SSM	LSM	SSM	LSM	SSM	LSM	SSM	LSM	SSM	LSM	
	%	%	%	%	%	%	%	%	%	%	
Heat-related illness and injuries increases the medical expenses of mining workers and their families	75.8	43.4	14.3	48.4	1.9	0.6	3.1	6.3	5.0	1.3	$\chi^2(4) = 50.123, p < .001, V = .396$
Tiredness and excessive sweating due to intensive mining work in hot environment increase the risk of drinking alcohol and energy drinks as well as substance abuse	32.3	43.4	49.7	32.1	3.7	1.3	6.2	11.3	8.1	11.9	$\chi^2(4) = 14.207, p < .001, V = .211$
Fatigue and weakness of mining workers due to intensive mining work in hot environment disrupts family life due to loss of leisure time	19.9	25.8	57.8	37.1	4.3	6.9	13.0	27.7	5.0	2.5	$\chi^2(4) = 19.064, p < .001, V = .244$
Erosion of income due to increased medical expense as a result of heat-related illness and injuries of mining workers increase the risk of family education, health and cohesion	21.1	22.0	16.8	48.4	44.1	8.8	11.8	18.2	6.2	2.5	$\chi^2(4) = 66.921, p < .001, V = .457$
Increased medical costs due to heat-related illness and injuries affect the social health and cohesion of mining workers and their family	19.3	34.0	19.9	44.7	38.5	1.3	18.0	18.2	4.3	1.8	$\chi^2(4) = 78.831, p < .001, V = .498$
Increase irritation, exhaustion, and lack of concentration of mining workers due to workplace heat exposure increase the risk of poor interpersonal relationship with co-worker, family and community	19.9	34.0	16.8	29.6	5.0	8.2	46.6	19.5	11.7	8.7	$\chi^2(4) = 31.234, p < .001, V = .312$
Heat-related illness and loss of productivity due to workplace heat exposure influence the social well-being and cohesion of mining workers, their families, co-workers, and communities	16.8	32.7	19.3	39.0	3.1	4.4	50.9	15.1	9.9	8.8	$\chi^2(4) = 50.437, p < .001, V = .397$
Workplace stress and frustration due to heat-related tiredness and illness influence alcoholism, smoking, substance abuse, and workplace and domestic violence	21.1	22.0	10.6	40.9	1.9	4.4	46.6	16.4	19.8	16.3	$\chi^2(4) = 54.095, p < .001, V = .411$

NB: n = 320; n (SSM) = 161; n (LSM) = 159.
Source: Field survey, 2017

machine will cease to operate. So, if I'm working in that situation and I realize I have exceeded my energy I cannot continue; definitely my output will not be enough to meet the target. So, it has a great impact on productivity (Participant, LSM workers).

4.5. Social well-being concerns

Occupational heat stress was shown to affect workers' social well-being. As revealed by the quantitative data, majority of workers of SSM and LSM answered positively that heat-related morbidity increased the medical expenses of mining workers and their families (>90%), tiredness and excessive sweating due to intensive work of mining in hot setting increased the risk of drinking alcohol and energy drinks as well as substance abuse (>75%), and fatigue and weakness of mining workers due to intensive mining work in hot environment disrupted family life due to loss of leisure time (above 62%) (Table 6). However, unequal proportions (SSM and LSM workers) were of the view that erosion of income due to increased medical expenses as a result of heat-related disease and injuries of mining workers increased the risk of family education and cohesion. Fewer SSM (37.9%) and much more LSM (70.4%) agreed, more SSM (44.1%) were undecided, while less SSM (18.0%) and more LSM (20.7%) disagreed to the statement. Similarly, as to whether increased medical costs due to heat-related illness and injuries affected the social healthiness and cohesion of mining workers and their family, fewer SSM (39.2%) and greater portion of LSM (78.7%) workers disagreed, more SSM (38.5%) and very few LSM (1.3%) workers were undecided, while more SSM (22.3%) and less LSM (20.1%) workers disagreed. Furthermore, based on the claim that increased irritation, exhaustion, and lack of concentration of mining workers due to workplace heat exposure increased the risk of poor interpersonal relationship with co-workers, family and community, less SSM (36.7%) and more LSM (63.6%) workers answered in support while more SSM (58.3%) and fewer LSM (28.2%) workers answered in disapproval. In addition, the assertion that heat-related illness and loss of productivity due to heat exposure in workplace influenced the social cohesion and well-being of mining workers, families and communities was supported by fewer SSM (36.1%) and much more LSM (71.7%) respondents. However, more SSM (60.8%) and few LSM (23.9%) workers did not support the statement. Last but not least, less SSM (31.7%) and more LSM (62.9%) workers claimed that workplace stress and frustration due to heat-related tiredness and illness influenced alcoholism, smoking, substance abuse and workplace and domestic violence. Nonetheless, more SSM (66.5%) and less LSM (32.8%) workers disagreed with the claim.

However, the contrast amongst SSM and LSM workers was statistically significant in heat-related morbidity increased the medical expenses of mining workers and their families ($p < .001$) by a small effect size, tiredness and excessive sweating due to intensive mining activity in hot setting increased the risk linked to drinking alcohol and energy drinks as well as substance abuse ($p < .001$) by a small effect size, and fatigue and weakness of mining workers due to intensive mining work in hot environment disrupted family life due to loss of leisure time ($p < .001$) by a small effect size, erosion of income due to increased medical expenses as a result of heat-related morbidity of mining workers increased the risk of family education and cohesion ($p < .001$) by a small effect size. Similar statistical significant disparity was evident in increased medical costs due to heat-related illness and injuries affected the social health and cohesion of mining workers and their family ($p < .001$) by a small effect size, increased irritation, exhaustion, and lack of concentration of mining workers due to workplace heat exposure increased the risk of poor interpersonal relationship with co-workers, family and community ($p < .001$) with a small effect size, heat-related illness and loss of productivity due to heat exposure at workplace influenced the social cohesion and well-being of mining workers, families and communities ($p < .001$) by a small effect size, and workplace stress and frustration due to heat-related tiredness and illness influenced alcoholism, smoking, substance abuse and workplace and domestic violence ($p < .001$) by a small effect size (Table 6). The workers disclosed that their experiences of heat stress affected the rate of interaction with their family and colleagues and fruitful coexistence. An example of the social well-being concerns of heat stress as expressed by a member of the FGD of the LSM, which supports the quantitative data is as follows:

Yes, it can affect them (family and colleagues) because when I fall sick or injured at work, it will affect my duties and other workers work. When I come home and am supposed to do some work or do some rounds with my family, because of the sickness, I may not get the time or energy to do what *am supposed to do. Even with your wife, once you have been to work for long like two weeks she may expect you to do something, and if you are not able to do it I think it will also maybe bring some quarrelling or she may not be happy with you and that will also affect your social life.*

Similarly, the concerns of work-related heat stress on the social well-being of mineworkers as expressed by a discussant of the SSM FGD is illustrated in the following text:

In the mining work, there is tiredness because of the hot weather. After a hard day's job under the sun or underground when you come home you want to rest but your family may ask you to do something like your children school's problems or their homework with these matters if you are tired you may be lazy or weak to do your responsibility…this does not bring fruitful coexistence.

5. Discussion

The study sought to understand Ghanaian mining workers' experiences of the social impacts of occupational heat stress and to ascertain whether there was any significant variation in the social impacts of work-related heat stress on mining workers between the type of mining activity or not. The experiences of occupational heat stress impacts on mining workers included heat-related morbidity, productive capacity loss, anxiety, slow pace of work, and inadequate social well-being. However, there was statistically significant difference in the workers' perceptions and experiences of work-related heat stress effects on their health and safety, psychological behavior, productivity and social well-being between the type of mining activity.

As evident in multiple studies (Kjellstrom et al., 2009b; Nunfam et al., 2018; Smith et al., 2014; Venugopal et al., 2016a, b; Xiang et al., 2014a; Xiang et al., 2014b), the mixed method approach yielded key themes (e.g., health and safety concerns, psychological and behavioral effects, productivity issues, and social well-being concerns) illustrating the social impacts of work-related heat stress on mining workers. Based on the use of between-method triangulation and complementarity, the study found convergence, corroboration and complementary occurrence between the quantitative and qualitative results on health concerns of heat stress on the workers (Denzin, 1978; Greene et al., 1989). For example, although the majority of workers as substantiated by the participants' lived experiences (e.g., heat-related disease and injuries) were worried about heat stress-induced health and safety consequences, statistically significant variation was found across the type of mining activity. Based on the conceptual association between occupational heat stress and well-being (Kjellstrom et al., 2016a, 2016b; Nunfam et al., 2019a; Parsons, 2014), the findings resonates with several empirical studies which underscores the physiological well-being repercussion of heat stress on workers exposed to hot and humid workplace settings (Acharya et al., 2018; Arbury et al., 2014; Flocks et al., 2013; Nunfam et al., 2018; Tawatsupa et al., 2012; Venugopal et al., 2016a, b; Xiang et al., 2014a; Xiang et al., 2014b). Thus, workers exposed to severe environmental conditions coupled with increased metabolic rate tend to experience physiological response to heat stress exemplified in health and safety concerns (heat exhaustion, heat cramps, heat rash, heat syncope and heat stroke) (Crimmins et al., 2017; Parsons, 2014).

The corroborated and complementary findings on mining workers' psychological and behavioral concerns of heat stress on account of merging the quantitative and qualitative results re-echo findings of similar studies (Lundgren et al., 2013; Nunfam et al., 2019a; Singh et al., 2015; Xiang et al., 2014b). For instance, as shown by the workers' lived experiences in the FGDs and majority of workers' views in the survey, it was found that occupational heat stress has serious implications for workers' actions, mindset and emotional conditions when working in hot and humid workplaces. The workers psychological behavior concerns tend to be worsened by their body's response to heat stress due to environmental conditions. However, the quantitative data revealed a statistically significant difference in psychological and behavioral concerns between SSM and LSM workers. Unlike MMR, a single method study may have exhibited inherent inadequacies in providing the breadth, length and depth of understanding the psychological and behavioral heat stress effect on mining workers (Creswell, 2015; Greene et al., 1989; Hesse-Biber, 2010).

Furthermore, heat stress effect on workers' productivity as indicated by the quantitative results, validated and complemented the qualitative findings. For instance, the participants' view provided insights into their experiences of productivity effect of heat stress while the survey revealed a significant difference in productivity effect of heat stress across the SSM and LSM workers, even though, the majority of workers (SSM and LSM) affirmed its consequences on productivity. The extent of holistic knowledge of how heat stress affects workers' productivity may not have been comprehensively understood in a single methods study, as illustrated in this MMR. Similarly, several studies (Krishnamurthy et al., 2017; Lao et al., 2016; Sahu et al., 2013; Venugopal et al., 2016a, b) have confirmed that work-related heat stress effects on workers' efficiency as this study highlights include reduced productive capacity, ineffective performance, decreased output, low energy, slow work pace, absenteeism and lack of concentration on account of heat-related illness and injuries.

Aside from impacting workers' health, psychological behavior and productivity, the physiological reaction to heat stress due to exposure to high temperature and humidity leads to social well-being consequences (Nunfam et al., 2018). Thus, on account of incorporating the qualitative and quantitative findings, the study showed that the discussants' perceived and actual experiences of work-based heat stress consequences on workers' social well-being were confirmed and complemented by most SSM and LSM workers' views in the survey. Nonetheless, a statistically significant discrepancy was found in the social well-being effects of heat stress between the type of mining activity as illustrated by the quantitative analysis. Thus, the use of MMR other than single method research yielded an enhanced understanding of work-related heat stress effect on the SSM and LSM workers' social well-being (Creswell, 2015; Greene et al., 1989). Considerably, the findings were consistent with various studies in which the consequences of occupational heat stress on workers' social well-being were associated with inadequate time for household tasks and family collapse due to heat-related fatigue, domestic violence and relational conflicts. Social well-being concerns of heat stress were also related to family income reduction, production losses and loss of job opportunities caused by heat-related illness, absenteeism, fatigue, and inadequate productive capacity (Nunfam et al., 2018; Venugopal et al., 2016a, b).

The insight into workers concerns (effects of health and safety, psychological behavior, productivity and social well-being) driven by work-related heat stress tends to inform supervisors and stakeholders on which adaptation strategies were important for policymaking and heat stress risk prevention and mitigation communication (Nunfam et al., 2019c). Therefore, it is significant to incorporate the safety, psychological behavior, productivity, health, and social well-being concerns of work-related heat stress of the workers into workplace and national health and safety strategies. The implementation of these policies creates the desired conducive work environments to reduce workers' susceptibility and enhance their resilience and adaptive capacity to heat stress-based safety and health consequences (Nunfam et al., 2019c). Based on rising temperature and global climate change, it also enriches the capability of national institutions working on climate-related health and safety issues in low-and middle-income countries to avert further burdens of health (Ebi & Otmani Del Barrio, 2017).

5.1. Implication and contribution to MMR and society

The study empirically demonstrates the feasibility of adopting contemporary characteristics of MMR including methodological eclecticism, paradigm heterogeneity, diverse research designs, analytical techniques and integration approach in assessing the social impacts of work-related heat stress on mineworkers in Ghana (Teddlie and Tashakkori, 2012). The use of a variety of methodologies that straddle between quantitative and qualitative research strategies presented the prospect to thoroughly investigate and obtain an in-depth understanding of the social impacts of occupational heat on mining workers (Tashakkori and Teddlie, 2011; Teddlie and Tashakkori, 2012). It also helped to overcome the inadequacies inherently associated with a single methodological (quantitative or qualitative) research approach (Creswell, 2015). Thus, despite the concerns that eclectic blend of methodologies is unworkable, this study supports the rejection of the inappropriateness and incompatibility proposition of combining qualitative and quantitative techniques in a single or series of studies (Denzin, 2008; Yanchar and Williams, 2006).

Furthermore, the study contributes to MMR by combining two philosophical paradigms (e.g., post-positivism and phenomenological research) to illustrate the practicability of paradigm heterogeneity which is typically associated with MMR (Teddlie and Tashakkori, 2012). Hence, this study used multiple paradigms to assess and accentuate the qualitative (e.g., depth of lived experiences and perceptions) and quantitative (e.g., breadth and differences) results on social impacts of work-related heat stress on mineworkers which may not have been revealed by a single paradigm approach.

Also, going by the tenets of convergent mixed methods, this study illustrated the appropriateness of employing multiple data collection methods (e.g., survey questionnaires and FGD guide) and integrated through mixing the confirmatory findings of the qualitative and quantitative data. The merging process provided the opportunity to compare and illustrate convergent, corroborative and complementary aspects of the study between the quantitative statistical results and qualitative excerpts from the FGDs.

Similarly, this study demonstrated the possibility of applying multiple methods as evident in the high degree of data integration and congruence between the qualitative and quantitative findings (Fetters et al., 2013). The observed concordance in the workers' safety and health concerns, psychological and behavioral effects, productivity issues, and concerns of social well-being that emerged from the qualitative and quantitative data mirror a high credibility level in the convergent MMR design and philosophy. Also, the congruence and adequate sense of complementarity in the quantitative and qualitative results enhanced and provided confidence in the research findings and conclusions (Hesse-Biber, 2010; Luyt, 2012).

Finally, this study has provided critical empirical research data on the practicality of mixed methods and contributes to extant knowledge on effects of work-related heat stress on workers' health and safety, productivity, behavior and psychosocial well-being. It also provides reliable data for appropriate stakeholders in the mining industry and society such as mining operators, employees, occupational health and safety officers and occupational hygienists as well as researchers and students interested in mixed methods research approach, workplace heat stress impacts and adaptation. It further fills the gap in heat exposure literature on the use of mixed methods to enhance our understanding of the social impacts of heat stress on mining workers, which could inform policy planning and implementation of programs to promote adaptation strategies.

5.2. Limitations of the study

Despite the significant contributions of the study as evident in the workers' perceptions and experiences of social impacts of work-related heat stress as well as the differences in work-related heat stress effects of health and safety, behavior, productivity and psychosocial well-being between the type of mining activity, it is also characterized by limitations. Accordingly, the study depended on respondents' perceptions and experiences of social impacts of occupational heat stress; but this could be associated with the likelihood of reminiscence bias. Also, the study respondents were recruited from mining operations situated in only one (i.e., Western Region) out of 16 regions in Ghana. Furthermore, the survey excluded susceptible workers (e.g., children) and those below permissible working age (under 18 years), workers without the ability to speak, read and write the English language, and not engaged in licensed gold mining. The relatively limited size and scope of respondents to only mining workers raises apprehensions of generalizability and representativeness of the results to similar cohort of workers exposed to the dangers and impact workplace heat exposure. Thus, it is imperative to remain cautious and not cavalier in the overall interpretation and generalization of the results of this study unless there are similar or cross-cultural studies among other cohorts of workers. Lastly, the study lacks substantial depth and scope to address workplace heat stress prevention and mitigation measures as to unearth solid evidence inform adequate adaptation policy options in the mining industry.

6. Conclusions and implications for policy decisions

The use of MMR characterized by methodological eclecticism, paradigm heterogeneity, and multiple research designs and methods including data gathering, analysis and amalgamation are feasible in occupational heat exposure studies. Multiple data gathering, analysis and combination possess the potential of enhancing our understanding of a complex phenomenon of the social impacts of work-related heat stress on mining workers, notwithstanding the growing use of mixed methods and integration challenges of results in MMR in Africa. Based on the evidence of integration of qualitative and quantitative strategies and data by merging, this study contributes to knowledge by affirming the practical application of between-method triangulation, convergence, corroboration, complementarity and weaving in MMR. It also adds value to gain a comprehensive knowledge and understanding of the social impacts of work-related heat stress on mineworkers as compared to the outcome of using a single method study. The high degree of corroboration and complementarity on account of merging the quantitative and qualitative findings resulted in key themes such as health and safety concerns, psychological and behavioral effects, productivity issues and social well-being concerns as social impacts of work-related heat stress on mining workers. The observed social impacts of work-related heat stress and the associated significant difference among the type of mining activity have the potential to inform national and workplace policy agenda on occupational heat stress information, communication and education, workplace health and safety awareness campaign in the mining industry. A concerted effort including employers, employees, and other stakeholders in any occupational heat stress management and adaptation policy decisions related to planning, formulation and implementation has the potential of reducing susceptibility to heat stress and boost the resilience and adaptive capacity of workers.

Declarations

Author contribution statement

Victor Fannam Nunfam: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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References

Acharya, P., Boggess, B., Zhang, K., 2018. Assessing heat stress and health among construction workers in a changing climate: a review. Int. J. Environ. Res. Publ. Health 15 (2), 247.

Arbury, S., Jacklitsch, B., Farquah, O., Hodgson, M., Lamson, G., Martin, H., Profitt, A., 2014. Heat illness and death among workers - United States, 2012-2013. Mmwr-Morb. Mortal. Wkly. Rep. 63 (31), 661–665. http://europepmc.org/articles/pmc4584656.

Biesta, G., 2010. Pragmatism and the philosophical foundations of mixed methods research. In: Sage Handbook of Mixed Methods in Social and Behavioral Research, 2, pp. 95–118.

Birchall, S.J., Murphy, M., Milne, M., 2016. Mixed methods research: a comprehensive approach for study into the New Zealand voluntary carbon market. Qual. Rep. 21 (7), 1351–1365.

Boring, E.G., 1953. The role of theory in experimental psychology. Am. J. Psychol. 66 (2), 169–184.

Bryman, A., 2006. Integrating quantitative and qualitative research: how is it done? Qual. Res. 6 (1), 97–113.

Campbell, D.T., Fiske, D.W., 1959. Convergent and discriminant validation by the multitrait-multimethod matrix. Psychol. Bull. 56 (2), 81–105.

Cohen, J., 1988. Statistical Power Analysis for the Behavioral Sciences. 1988, Hillsdale, NJ (Vol. 2).

Creswell, J.W., 2013. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. Sage publications, London.

Creswell, J.W., 2015. A Concise Introduction to Mixed Methods Research. SAGE publications.

Creswell, J.W., Plano Clark, V.L., 2017. Designing and Conducting Mixed Methods Research. Sage publications.

Crimmins, A., Balbus, J., Gamble, C., Beard, C., Bell, J., Dodgen, D., Eisen, R., Fann, N., Hawkins, M., Herring, S., 2017. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. US Global Change Research Program, Washington DC, 2016.

Denzin, N.K., 1978. The Research Act: A Theoretical Introduction to Sociological Methods. Praeger, New York.

Denzin, N.K., 2008. The new paradigm dialogs and qualitative inquiry. Int. J. Qual. Stud. Educ. 21 (4), 315–325.

Dutta, P., Rajiva, A., Andhare, D., Azhar, G.S., Tiwari, A., Sheffield, P., Climate Study, G., 2015. Perceived heat stress and health effects on construction workers. Indian J. Occup. Environ. Med. 19 (3), 151–158.

Ebi, K.L., Otmani Del Barrio, M., 2017. Lessons learned on health adaptation to climate variability and change: experiences across low- and middle-income countries. Environ. Health Perspect. 125 (6), 065001.

Fetters, M.D., Curry, L.A., Creswell, J.W., 2013. Achieving integration in mixed methods designs—principles and practices. Health Serv. Res. 48 (6pt2), 2134–2156.

Fetters, M.D., Freshwater, D., 2015. The 1+ 1= 3 integration challenge. In: SAGE Publications Sage CA: Los Angeles, CA.

Fetters, M.D., Molina-Azorin, J.F., 2019. New requirements to include the methodological contribution in articles published in the journal of mixed methods research. In: SAGE Publications Sage CA: Los Angeles, CA.

Frimpong, K, Odonkor T, S, Kuranchie A, F, Nunfam F, V, 2020. Evaluation of heat stress impacts and adaptations: perspectives from smallholder rural farmers in Bawku East of Northern Ghana. Heliyon 6 (4), e03679. https://doi.org/10.1016/j.heliyon.2020.e03679.

Frimpong, K, Van Etten J, E, Oosthuzien, J, Nunfam F, V, 2017. Heat exposure on farmers in northeast Ghana. Int. J. Biometeorol. 61 (3), 397–406. https://doi.org/10.1007/s00484-016-1219-7.

Flocks, J., Vi Thien Mac, V., Runkle, J., Tovar-Aguilar, J.A., Economos, J., McCauley, L.A., 2013. Female farmworkers' perceptions of heat-related illness and pregnancy health. J. Agromed. 18 (4), 350–358.

Ghana Chamber of Mines (GCM), 2018. Performance of the Mining Industry in 2017. Retrieved from Accra, Ghana: https://ghanachamberofmines.org/wp-content/uploads/2016/11/Performance-of-the-Industry-2017.pdf.

Greene, J.C., 2006. Toward a methodology of mixed methods social inquiry. Res. Sch. 13 (1), 93–98.

Greene, J.C., 2015. Preserving distinctions within the multimethod and mixed methods research merger. In: The Oxford Handbook of Multimethod and Mixed Methods Research Inquiry.

Greene, J.C., Caracelli, V.J., Graham, W.F., 1989. Toward a conceptual framework for mixed-method evaluation designs. Educ. Eval. Pol. Anal. 11 (3), 255–274.

Guetterman, T.C., Fetters, M.D., Creswell, J.W., 2015. Integrating quantitative and qualitative results in health science mixed methods research through joint displays. Ann. Fam. Med. 13 (6), 554–561.

Hesse-Biber, S.N., 2010. Mixed Methods Research: Merging Theory with Practice. Guilford Press.

Johnson, R.B., Onwuegbuzie, A.J., 2004. Mixed methods research: a research paradigm whose time has come. Educ. Res. 33 (7), 14–26.

Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., Hyatt, O., 2016a. Heat, human performance, and occupational health: a key issue for the assessment of global climate change impacts. Annu. Rev. Publ. Health 37, 97–112.

Kjellstrom, T., Gabrysch, S., Lemke, B., Dear, K., 2009a. The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies. Glob. Health Action 2.

Kjellstrom, T., Holmer, I., Lemke, B., 2009b. Workplace heat stress, health and productivity - an increasing challenge for low and middle-income countries during climate change. Glob. Health Action 2, 46–51.

Kjellstrom, T., Otto, M., Lemke, B., Hyatt, O., Briggs, D., Freyberg, C., Lines, L., 2016b. Climate Change and Labour : Impacts of Heat in the Workplace Climate Change, Workplace Environmental Conditions, Occupational Health Risks, and Productivity –an Emerging Global challenge to Decent Work, Sustainable Development and Social Equity. Retrieved from. http://www.ilo.org/wcmsp5/groups/public/—ed_emp/—gjp/documents/publication/wcms_476194.pdf.

Krejcie, R.V., Morgan, D.W., 1970. Determining sample size for research activities. Educ. Psychol. Meas. 30 (3), 607–610.

Krishnamurthy, M., Ramalingam, P., Perumal, K., Kamalakannan, L.P., Chinnadurai, J., Shanmugam, R., Venugopal, V., 2017. Occupational heat stress impacts on health and productivity in a steel industry in southern India. Saf Health Work 8 (1), 99–104.

Lao, J., Hansen, A., Nitschke, M., Hanson-Easey, S., Pisaniello, D., 2016. Working smart: an exploration of council workers' experiences and perceptions of heat in Adelaide, South Australia. Saf. Sci. 82, 228–235.

Lundgren, K., Kuklane, K., Gao, C.S., Holmer, I., 2013. Effects of heat stress on working populations when facing climate change. Ind. Health 51 (1), 3–15.

Luyt, R., 2012. A framework for mixing methods in quantitative measurement development, validation, and revision: a case study. J. Mix. Methods Res. 6 (4), 294–316.

Maula, M., Stam, W., 2019. Enhancing Rigor in Quantitative Entrepreneurship Research, pp. 1–32.

McQuilken, J., Hilson, G., 2016. Artisanal and Small-Scale Gold Mining in Ghana Evidence to Inform an 'action Dialogue'. Retrieved from London. https://pubs.iied.org/16618IIED/.

Mertens, D.M., 2003. Mixed methods and the politics of human research: the transformative-emancipatory perspective. In: Handbook of Mixed Methods in Social and Behavioral Research, pp. 135–164.

Mertens, D.M., 2015. Mixed methods and wicked problems. J. Mix. Methods Res. 9 (1), 3–6.

Miller, F., 2014. Too hot to handle: assessing the social impacts of extreme heat. In: Paper Presented at the Turning up the Heat:A Symposium for SIA Practitioners and Researchers.

Ngulube, P., 2010. Mapping mixed methods research in library and information science journals in Sub-Saharan Africa 2004–2008. Int. Inf. Libr. Rev. 42 (4), 252–261.

Ngulube, P., Ngulube, B., 2015. Mixed methods research in the South African journal of economic and management sciences: an investigation of trends in the literature. S. Afr. J. Econ. Manag. Sci. 18 (1), 1–13.

Ngwenya, B, Oosthuizen, J, Cross, M, Frimpong, K, 2018. Emerging heat-related climate change influences; a public health challenge to health care practitioners and policy makers: insight from Bulawayo, Zimbabwe. International Journal of Disaster Risk Reduction 27, 596–601. https://doi.org/10.1016/j.ijdrr.2017.10.012.

Nunfam, V.F., 2019. Social Impacts of Climate Change and Occupational Heat Stress and Adaptation Strategies of Mining Workers in Ghana. https://ro.ecu.edu.au/theses/2273.

Nunfam, V.F., Adusei-Asante, K., Frimpong, K., Van Etten, E.J., Oosthuizen, J., 2020. Barriers to occupational heat stress risk adaptation of mining workers in Ghana. Int. J. Biometeorol. 1–17.

Nunfam, V.F., Adusei-Asante, K., Frimpong, K., Van Etten, E.J., Oosthuizen, J., 2020a. Barriers to occupational heat stress risk adaptation of mining workers in Ghana. Int. J. Biometeorol. 64, 1085–1101.

Nunfam, V.F., Adusei-Asante, K., Van Etten, E.J., Oosthuizen, J., Adams, S., Frimpong, K., 2019a. The nexus between social impacts and adaptation strategies of workers to occupational heat stress: a conceptual framework. Int. J. Biometeorol. 63 (291), 1–14.

Nunfam, V.F., Afrifa-Yamoah, E., Adusei-Asante, K., Van Etten, E.J., Frimpong, K., Mensah, I.A., Oosthuizen, J., 2021. Construct validity and invariance assessment of the social impacts of occupational heat stress scale (SIOHSS) among Ghanaian mining workers. Sci. Total Environ. 771.

Nunfam, V.F., Oosthuizen, J., Adusei-Asante, K., Van Etten, E.J., Frimpong, K., 2019b. Perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana. Sci. Total Environ. 657, 365–378.

Nunfam, V.F., Van Etten, E.J., Oosthuizen, J., Adusei-Asante, K., Frimpong, K., 2019c. Climate change and occupational heat stress risks and adaptation strategies of mining workers: perspectives of supervisors and other stakeholders in Ghana. Environ. Res. 169, 147–155.

Nunfam, V.F., Adusei-Asante, K., Van Etten, E.J., Oosthuizen, J., Frimpong, K., 2018. Social impacts of occupational heat stress and adaptation strategies of workers: a narrative synthesis of the literature. Sci. Total Environ. 643, 1542–1552.

Parsons, K., 2014. Human thermal Environments: the Effects of Hot, Moderate, and Cold Environments on Human Health, comfort, and Performance, 3 ed. CRC Press, Boca Raton, NewYork and London.

Plano Clark, V.L., Ivankova, N.V., 2016. Mixed Methods Research: A Guide to the Field. Sage Publications. Vol. 3.

Podsakoff, P.M., MacKenzie, S.B., Podsakoff, N.P., 2012. Sources of method bias in social science research and recommendations on how to control it. Annu. Rev. Psychol. 63, 539–569.

Sahu, S., Sett, M., Kjellstrom, T., 2013. Heat exposure, cardiovascular stress and work productivity in rice harvesters in India: implications for a climate change future. Ind. Health 51 (4), 424–431.

Sarantakos, S., 2012. Social Research. Palgrave Macmillan.

Sawilowsky, S.S., 2009. New effect size rules of thumb. J. Mod. Appl. Stat. Metho. 8 (2), 597–599.

Sieber, S.D., 1973. The integration of fieldwork and survey methods. Am. J. Sociol. 78 (6), 1335–1359.
Singh, S., Hanna, E.G., Kjellstrom, T., 2015. Working in Australia's heat: health promotion concerns for health and productivity. Health Promot. Int. 30 (2), 239–250.
Smith, K.R., Woodward, A., Campbell-Lendrum, D., Chadee, D.D., Honda, Y., Liu, Q., Sauerborn, R., 2014. Human health: impacts, adaptation, and co-benefits. Climate Change 709–754. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap11_FINAL.pdf.
Tanyanyiwa, V.I., Kanyepi, T., 2015. Mixed methods research strategies in climate change adaptation in Mt Darwin district, Zimbabwe. Int. J. Innovat. Res. Develop. 4 (9). ISSN 2278–0211.
Tashakkori, A., Teddlie, C., 2010. Sage Handbook of Mixed Methods in Social & Behavioral Research. sage.
Tashakkori, A., Teddlie, C., 2011. Mixed Methods Research: Contemporary Issues in an Emerging Field. The Sage Handbook of Qualitative Research, pp. 285–300.
Tashakkori, A., Teddlie, C., Teddlie, C.B., 1998. Mixed Methodology: Combining Qualitative and Quantitative Approaches. Sage, Thousand Oaks, CA. Vol. 46.
Tawatsupa, B., Lim, L.L., Kjellstrom, T., Seubsman, S.-a., Sleigh, A., Team, T.C.S., 2012. Association between occupational heat stress and kidney disease among 37 816 workers in the Thai Cohort Study (TCS). J. Epidemiol. 22 (3), 251–260.
Teddlie, C., Tashakkori, A., 2012. Common "core" characteristics of mixed methods research: a review of critical issues and call for greater convergence. Am. Behav. Sci. 56 (6), 774–788.
Tehseen, S., Ramayah, T., Sajilan, S., 2017. Testing and controlling for common method variance: a review of available methods. J. Manag. Sci. 4 (2), 142–168.
Teye, J.K., 2012. Benefits, challenges, and dynamism of positionalities associated with mixed methods research in developing countries: evidence from Ghana. J. Mix. Methods Res. 6 (4), 379–391.
Vanclay, F., 2003. International principles for social impact assessment. Impact Assess. Proj. Apprais. 21 (1), 5–12.
Vanclay, F., Esteves, A.M., Aucamp, I., Franks, D.M., 2015. Social Impact Assessment: Guidance for Assessing and Managing the Social Impacts of Projects. Fargo ND: International Association for Impact Assessment.
Venugopal, V., Chinnadurai, J., Lucas, R., Kjellstrom, T., 2016a. Occupational heat stress profiles in selected workplaces in India. Int. J. Environ. Res. Publ. Health 13 (1), 89.
Venugopal, V., Chinnadurai, J., Lucas, R., Vishwanathan, V., Rajiva, A., Kjellstrom, T., 2016b. The social implications of occupational heat stress on migrant workers engaged in public construction: a case study from southern India. Int. J. Constr. Environ. 7 (2).
Webb, E.J., Campbell, D.T., Schwartz, R.D., Sechrest, L., 1999. Unobtrusive Measures. Sage Publications. Vol. 2.
Xiang, J., Bi, P., Pisaniello, D., Hansen, A., 2014a. Health impacts of workplace heat exposure: an epidemiological review. Ind. Health 52 (2), 91–101.
Xiang, J., Bi, P., Pisaniello, D., Hansen, A., Sullivan, T., 2014b. Association between high temperature and work-related injuries in Adelaide, South Australia, 2001–2010. Occup. Environ. Med. 71 (4), 246–252.
Xiang, J., Hansen, A., Pisaniello, D., Bi, P., 2015. Perceptions of workplace heat exposure and controls among occupational hygienists and relevant specialists in Australia. PloS One 10 (8), e0135040.
Xiang, J., Hansen, A., Pisaniello, D., Bi, P., 2016. Workers' perceptions of climate change related extreme heat exposure in South Australia: a cross-sectional survey. BMC Publ. Health 16 (1), 549.
Yanchar, S.C., Williams, D.D., 2006. Reconsidering the compatibility thesis and eclecticism: five proposed guidelines for method use. Educ. Res. 35 (9), 3–12.