A Thesis on

EVALUATING THE IMPACT OF CLIMATE CHANGE ON CONSTRUCTION SITE WORKERS PRODUCTIVITY AND SAFETY

Submitted in the partial fullfillment of the award of

Master of Technology

in

CONSTRUCTION TECHNOLOGY &MANAGEMENT

By

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Session:2021-2022

DECLARATION

I declare that the dessertation entitled **"Evaluating the impact of climate change on construction workers productivity "** is the bonafide research work carried out by me, under the guidance of **Mr. Mohd Asim, Assistant Professor, Department of Civil Engineering, Integral University, Lucknow.** Further I declare that this has not previously formed the basis of award of any degree, diploma, associate-ship or other similar degrees or diplomas, and has not been submitted anywhere else**.**

Date:

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CERTIFICATE

Certified that the dessertation entitled **"Evaluating the impact of climate change on construction site workers productivity and safety"** *is being submitted by* ***Mr. Mohd Amaan Alam (Roll no: 2001103003)*** *in partial fulfillment of the requirement for the award of degree of Master of Technology (Construction Technology And Management) of Integral University, Lucknow , is a record of candidate's own work carried out by his under my supervision and guidance.*

The results presented in this thesis have not been submitted to any other university or institute for the award of any other degree or diploma.

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ACKNOWLEDGEMENT

First, I wish to express my sincere gratitude to my supervisor **Mr. Mohd Asim** for his enthusiasm, patience, insight comments, helpful information and practical advice that has helped me in completing my dessertation **“Evaluating the impact of climate change on construction site workers productivity and safety"** successfully.

I would also like to thank to **Dr. Syed Aqeel Ahmad, Professor and Head of Department Civil Engineering** for his encouragment during the Project. I would also like to thank to all the faculty staff of Civil Engineering department.

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TABLE OF CONTENTS

Abstract

The literature on the potential impacts of climate change on the health of outdoor workers has received limited attention as a whole, and in sub-Saharan African countries in particular. Yet, substantial numbers of workers are experiencing the health effects of elevated temperature, in combination with changes in precipitation patterns, climate extremes and the effects of air pollution, which have a potential impact on their safety and wellbeing. With increased temperatures within urban settlements and frequent heats waves, there has been a sudden rise in the occurrence of heat-related illness leading to higher levels of mortality, as well as other adverse health impacts. This paper discusses the impacts of extreme heat exposure and health concerns among outdoor workers, and the resultant impacts on their productivity and occupational safety in tropical developing countries with a focus on Sub-Saharan Africa, where there is a dearth of such studies. Aside from the direct effects caused by extreme heat exposure, other indirect health hazards associated with increasing heat among this group includes exposures to hazardous chemicals and other vector-borne diseases. In addition, reduced work capacity in heat-exposed jobs will continue to rise and hinder economic and social development in such countries. There is an urgent need for further studies around the health and economic impacts of climate change in the workplace, especially in tropical developing countries, which may guide the implementation of the measures needed to address the problem.

Chapter 1

Introduction & scope of study

Global climate change is among the most visible environmental concerns of the 21st century and these changes have the potential to affect human health, both directly and indirectly. Urban centers in most developing countries are now witnessing rapid population growth. According to the United Nations, the world's urban population is expected to increase to about 57% by 2050. Developing countries will account for more than 90% of future population growth experienced within its cities. With this projection of population growth, the WHO has urged its member states to take decisive action aimed at addressing the health impacts associated with climate change. Despite being one of the most recognized contemporary and future global environmental issues, climate change impacts and it's adverse aspects to human lives, including occupational safety, have received surprisingly little attention. Because of the rapid global urbanization trend, urban heat island (UHI) phenomena are now part of the climatological effects resulting from human activities on the urban environment.

Kiefer et al., argued that, despite the existence of considerable research and planning with regard to the public health and environmental aspects of climate change, there is little effort focused on its effects on workers' health and safety. Workers, especially those working outdoors, are often the first to be exposed to the effects of climate change. They may be exposed for longer durations and at greater intensities which in the long run could result in the increase in prevalence and severity of known occupational hazards and exposures, and also the emergence of new ones. Previous research has shown that climate change can contribute to a decrease in the ozone layer and affect UV radiation levels at the surface of the earth. This can cause outdoor workers to experience more frequent, intense, and longer exposure to UV radiation, resulting in an increased risk of adverse eye effects, skin cancer, and possibly immune dysfunction. In addition, exposure to higher temperatures with more frequent periods of heat may result in greater heat stress, potentially leading to more cases of heat-related illnesses such as heat stroke, heat exhaustion, increased susceptibility to chemical exposure, and fatigue. Exposure to increased temperature can

also result in reduced vigilance creating an increased risk of injury or lapses in safety. Furthermore, elevated temperatures can increase levels of air pollution, including ground-level ozone; outdoor workers have longer exposure to such air pollutants, which are linked to chronic health effects, such as respiratory diseases and allergic reaction

The report compiled by TUC has acknowledged that climate changes are expected to bring about both risks and opportunities to every sector of the country's economy. In the energy sector, for instance, the direct impact of climate change could result in power plant flooding, leading to power cuts affecting other economic sectors and on the demand side, energy use for indoor cooling during the summer is expected to increase. Workers required to respond to problems that may arise could be placed at higher risk during these extreme weather events. Seven categories of climate-related hazards—increased ambient temperature, air pollution, ultraviolet exposure, extreme weather, vector-borne diseases and expanded habitats, industrial transitions and emerging industries and changes in the built environment at work—have been the subject of climate change assessments on the health of outdoor workers in several studies There has been an increasing concern around the impact of extreme heat on both indoors and outdoors workers health and safety due to increased heat and climate change s pointed out by St. Louis and Hess the health impact of climate change will not be distributed uniformly, but rather it is expected that the distribution patterns of health burdens will be increased around the globe.

The purpose of the paper is to summarize the existing knowledge and synthesize the impact of climate change adaptation and occupational health and safety. In order to achieve this, the paper provides concise a review concerning new findings around relevant health impacts associated with climate change, extreme heat exposure and comments on different adaptation strategies available to decision makers to alleviate the impact of climate change factors and outdoor workers' productivity. Due to limited research work carried out in tropical developing countries, especially in sub-Saharan Africa, the paper aims to draw more research attention around emerging research areas as they relate to the impact of extreme heat exposure, climate change adaptation measures and health and safety concerns among outdoor workers (individuals that spend more than 4 h working outside) within these countries. It will consider the likelihood of effects on their productivity and occupational safety. Aside from the direct impact caused by extreme heat

exposure, other indirect health hazards associated with increasing heat among this group include exposure to hazardous chemicals and other vector diseases, which will also be addressed. By proposing micro-adaptation alternatives, this study will help policymakers adopt effective means of meeting the challenges posed by climate change exposure.

1.1 study objective

To evaluate the expected effect on work limit of construction workers with respect to individuals presented working to expanding heat because of environmental change.

1.2 climate change and construction workers productivity

Heat influences the complete usefulness of the workforce (Heal and Park, 2016) in three ways: (I) work supply, that is, the total hours that people decide to work, (ii) work exertion, that is, how much exertion laborers decide to use while at work, and (iii) work efficiency, that is, how much specialists' adequacy is debased while working.

The bits of knowledge of these exact investigations can be consolidated into a constant connection between work usefulness and heat exposure. These reaction capacities regularly measure usefulness misfortune either as a rate worth of full efficiency or as rate efficiency misfortune comparative with full efficiency. The most well-known proportion of heat exposure is the 'Wet Bulb Globe Temperature' (WBGT) record. The WBGT is a weighted normal of various heat measures (wet bulb, dark globe, and air temperature) that mirrors the joined impact of temperature, stickiness, daylight, and wind on the presentation of competitors, warriors, and outside laborers (Epstein and Moran, 2006; Lemke and Kjellstrom, 2012). The WBGT list isn't the main proportion of heat stress. Options, which likewise reflect factors like acclimatization, incorporate the Excess Heat Factor (Hatvani-Kovacs, Belusko, Pockett, and Boland, 2016), studies and self-appraisals (Zander, Moss, and Garnett, 2017), or relationship between emergency clinic records and labourer pay and temperature levels (Xiang, Bi, Pisaniello, and Hansen, 2014). Notwithstanding, WBGT is an easy-to-use, ordinarily utilized, and broadly comprehended strategy for evaluating pressure in hot warm conditions (D'Ambrosio Alfano, Palella, and Riccio, 2012).

Adhvaryu, Kala, and Nyshadham (2020) exploit variety in work environment temperatures initiated by low-heat LED lighting and reason that specialist efficiency increments when

temperatures are diminished. Hsiang (2010) presents a meta examination of late research facility proof that shows that once WBTs transcend 25°C, task effectiveness seems to fall by roughly 1%–2% per degree. A WBT of 25°C at 65% relative mugginess is generally comparable to a temperature of 31°C in dry conditions. Work environment efficiency to the side, high temperatures may likewise lessen our eagerness and capacity to try and be available working. Substantially less early proof exists on non-attendance, despite the fact that Zivin and Neidell (2014) see that individuals in the United States dispense less an ideal opportunity to work in uncovered enterprises when temperatures are exceptionally high. There have been various examinations in the physiology and designing writing that see that high temperatures decrease work usefulness.

1.3 physiological and clinical impressions of heat exposure

The human body is intended to keep a center internal heat level of 37 °C. An individual completing actual effort (for case while working) makes metabolic hotness inside the body, which should be moved to the individuals outside territory to stay away from a perilous increment of center internal heat level (Parsons K, 2003). The body heat balance is dictated by the six crucial factors (Parsons K, 2003): air temperature; brilliant temperature; dampness; air development (wind speed); Garment; and the metabolic hotness produced by mortal actual effort.

Working in a hot climate could prompt heat stress, as thermoregulation falls flat or is essentially lacking, causing heat-related ailment (HRI). HRI can prompt hyperthermia, hyponatremia, heat cramps, heat rash, heat weariness, heatstroke, and even passing. The indications of HRI are thirst, sickness, retching, unsteadiness, extreme perspiring, sweat rashes, shortcoming, raised internal heat level, torment, fits, and muscle cramps (Jacklitsch B, Williams J, Musolin K, Coca A, Kim J-H, Turner N, 2016).

All things considered, the metabolic hotness age should be decreased to stay away from heat strain and hotness stroke (Ramsey JD, Bernard TE, 2000), If cooling by means of perspiring and convection (through contact with cooler air and air development) isn't adequate. This makes cutoff points to the degree to which actual effort and work issue can be kept up with without rest periods. At the point when actual effort is high in a hot working landscape, the specialist is at inconvenience of expanded center internal heat level (over 38 °C), brought down actual work limit.

Chapter 2

Literature Reviews

A narrative review of previously published literature was undertaken to generate data that support the development of the work. A broad perspective on the subject was taken in the review, that helps to describe the impacts of climate change, adaptation and occupational health and safety concerns among outdoor workers.

Search Strategy and Sources of Information

The study adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to identify relevant materials for inclusion in the study. To identify relevant peer reviewed articles and grey documents we searched the Google Scholar, PubMed, Medline and Web of Science databases from January 2002 to March 2019 for studies that assessed the impact of climate change on workers' health and productivity.

1)There are several challenging engineering and management problems that occur on construction sites.

2) These problems affect the time, budget and plans, and specifications (Trauner, 1993) and often cause defects, disputes and delays (Clarke, 1988).

3) According to Holroyd (1999) many construction site procedures and methods have not changed over the years and the same mistakes are being repeated.

4) The main reasons are because the site management is characterised by high work overload, long working hours and many conflicting parties to deal with, including the management of the sub-contractors and liaison with the clients (Griffith and Watson, 2004).

5) For instance, the problems identified within site management practices can be categorised into three main categories: management and administration problems; technical and engineering problems; and site communication problems.

6) Occupational safety and health research should be expanded. It should include (a) investigating climate change-related hazards and at-risk populations; (b) using surveillance data on diseases, injuries, and occupational hazards to guide research agendas; and (c) developing, implementing, and evaluating new adaptation measures (Adam-Poupart et al., 2013; Schulte & Chun, 2009).

7) Public health surveillance is the "ongoing, systematic collection, analysis, and interpretation of health data, essential to the planning, implementation, and evaluation of public health practice, closely integrated with the dissemination of these data to those who need to know " (National Academies of Sciences, Engineering, and Medicine p. 21).

8) Surveillance can be used to identify the impact of climate change on worker health; to help establish research agendas; and to help plan, implement, and evaluate preventive measures. Data from "sentinel events" due to climate change can be analyzed so that lessons can be learned to prevent similar problems in the future (Pierce,).

9) Current public health surveillance systems that depend upon employers' reports to government agencies are not sufficient to detect the impacts of climate change on workers' health (Harduar Morano et al. New approaches will be needed. For example, data from emergency departments may be necessary for surveillance of worker injuries due to extreme weather events, such as storms and heat waves (Harduar Morano et al.; Ochsner et al..

10) In the United States, the Council of State and Territorial Epidemiologists is addressing this need by developing climate-change indicators that could obtain data related to occupational health and safety problems (English et al; Harduar Morano et al.

Chapter : 3

Research Methodology

3.1 Work plan

A narrative review of previously published literature was undertaken to generate data that support the development of the work. A broad perspective on the subject was taken in the review, that helps to describe the impacts of climate change, adaptation and occupational health and safety concerns among outdoor workers.

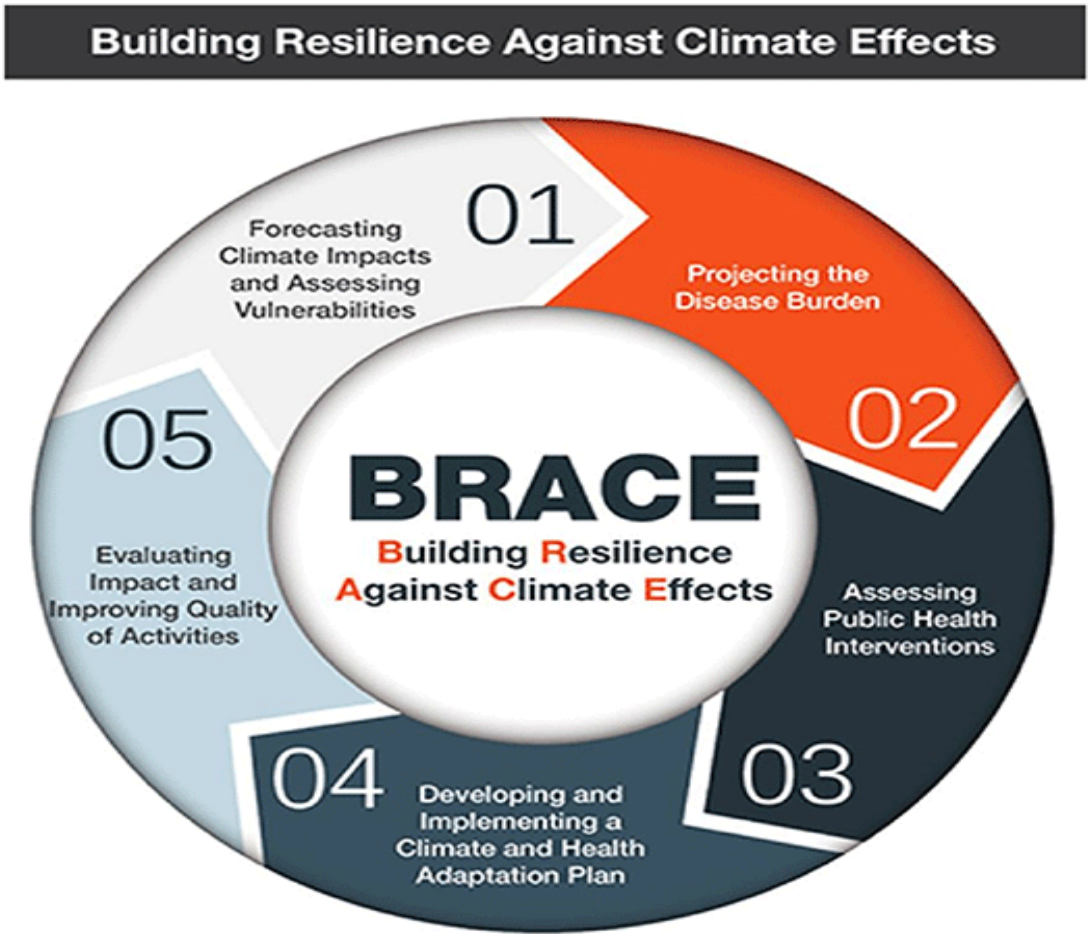

Figure 1

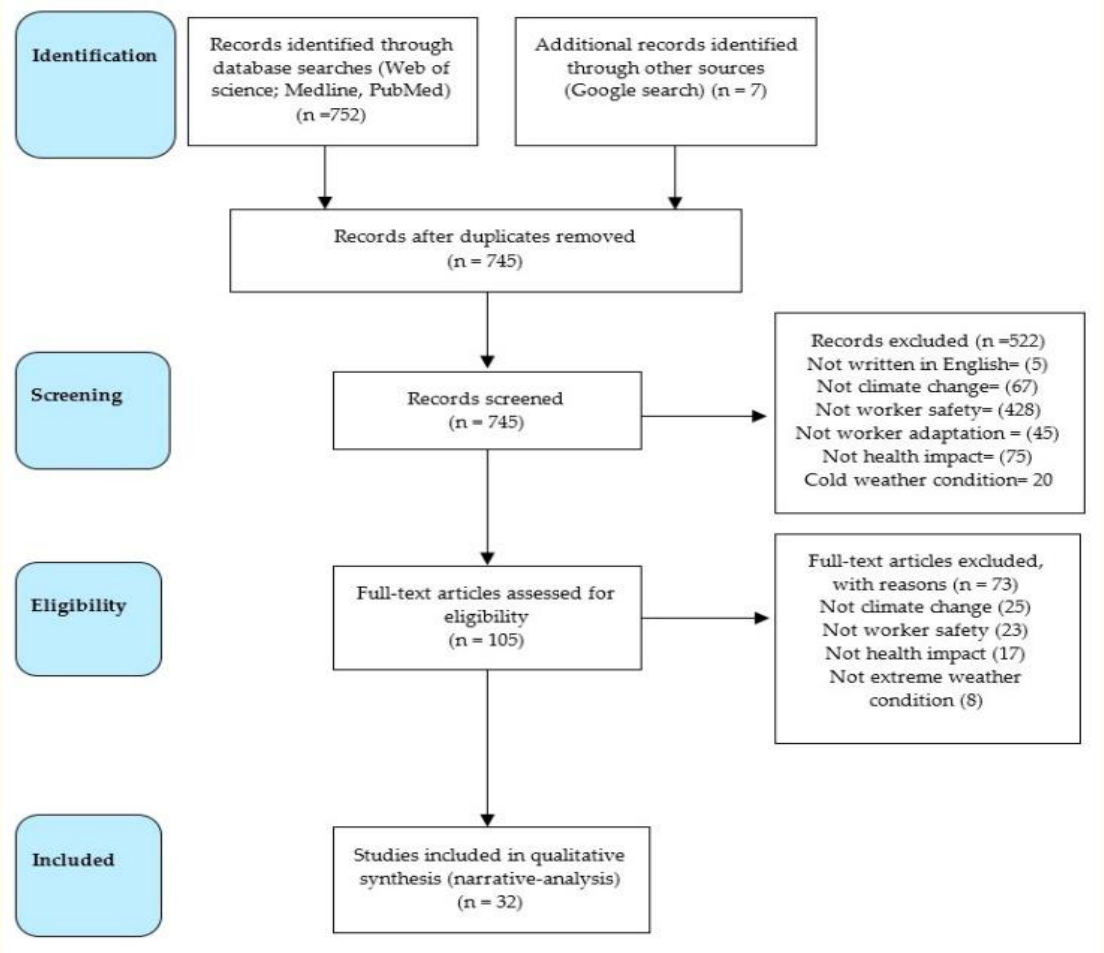

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Figure 1

Adopted PRISMA flowchart providing insights as to how the studies were selected [19].

Keywords used during each search included ‘climate change impact’ and; ‘urban heat island’, ‘extreme heat’, ‘heat strain and health’ heat stress and productivity’, ‘outdoor workers health’, ‘occupational health and safety’, ‘health and safety’, ‘adaptation’. Only articles that meet the needs of the present paper regarding climate change impacts on workers safety (hazards, risk) and health (disease, chemical exposure, and zoonosis) were considered.. Further exclusion criteria considered are presented in Table 1.

Table 1

Inclusion and exclusion criteria considered in the selection of studies.

Inclusion Criteria	Exclusion Criteria
Study outcome that considers either quantitative, qualitative and mixed-method approaches	Comments, letters, editorials, viewpoints, reviews, reports, and correspondence
Peer-reviewed journal articles published in English language	Articled that are published in other languages
Studies on climate change impact on workers' health and safety, heat stress and heat strain, adaptation strategies	Climate change-related studies that places emphasis only on storms, rainfall, drought, cyclones, and rising sea levels
Studies that considered the impact of urban heat island effect on workers' health and wellbeing	Articles that are not related to the context of the study
Assessment of occupational heat stress on psychological and social well-being	Studies only on the effect of climate change and heat stress on plants, animals, and crops
Studies on barriers of workers to occupational heat stress adaptation	Studies using only secondary data without primary data

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2.2. Characteristics of the Considered Studies

The characteristics of the studies here reviewed include ten entries for each: article type, study design, data sources, analysis method, study aim; study population, study theme, intervention, outcome data and outcome measures. Table 2 provides a detailed overview of the 32 studies considered in the review. Geographically the studies varied widely across the countries of the continents of Africa, Asia, Europe, North and Central America and Australia, so as to ensure a wide international basis, hence adding robustness to the findings. The designs varied among the

studies and included empirical evidence, systematic reviews; scenario-based assessments, narrative reviews; exploratory studies; survey-based studies; formative research, case studies and ecological study design. Other measures considered in the appraisal of selected studies included reporting style, outcome measures, study design, the fidelity of protocol and possible conflicts of interest.

Table 2

Characteristics of the materials included in the review.

Author and Year	**Study Design**	**Analysis Methods**	**Study Aim**	**Study Populations**	**Study Theme**	**Study Intervention**	**Outcome Data**	**Outcome Measure**
Applebaum et al.	Empirical evidence	Mixed methods	Overview on exposure to climate change elements and vulnerable occupational sectors	US workers	Occupational risk and climate change impacts	Climate change threats to workers	Anticipation of how workers will be susceptible to climate change impacts	National research agenda around control and mitigation of workers susceptibility to climate change
Flouris et al.	Systematic review	Mixed methods	Develop policies and progra	Varied	Environmental heat strain and	Review on occupation heat strain on	Single shift workers working under	Actions to mitigate climate change

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			mmes aimed at assessig climate change impacts on health, economics and social benefit		worker productivity and health effects	workers' health and productivity	heat stress are more likely to experience occupational heat strain	effects and anticipated rise in heat stress
Balbus et al.	Scenario based assessments	Not stated	Association between global climate change, chemical spread and risk to human health	Varied	Global climate change and the use and spread of chemical in the environment	Influence of global climate change on the exposure to chemicals and their resultant health impacts	Review of policies to address global climate change influence on chemical risk	Generation of Improved data set to determine human exposure to chemical matrix associated with climate

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
								change variability
Xiang et al.	Cross-sectional survey	quantitative method	Investigation of workers' extreme heat exposure perceptions and behavioural responses in warm climate	Varied	Climate change, heat stress, workplace heat exposure, and work-related injuries	Impact of climate change and workers' perceptions and attitudes towards workplace heat exposure	The need to strengthen workers' heat risk awareness and refine current heat prevention strategies in a warming climate	Promotion of educational programmes and training among varied workforce especially the those with limited education level
Messeri et al.	Case study	Mixed methods	Assessment of impact of culture on heat-	Migrant workers	Migrant occupational risk, heat waves	Assessment of perceive high temperature risk	Ethnical differences on heat stress percepti	Not stated

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			stress perception and management among native and immigrant workers		and heat perception	in workplace among different worker force	on and adaptation strategies	
Mathee et al.	Pilot study	Mixed methods	Assessment of outdoor workers perceptions of hot weather and the impacts on their health and productivity levels	Varied	Climate change, global warming impact on outdoor workers health and productivity	Assessment of potentials workforce populations current adaptation measures to cope with hot weather	Poor coping ability in very hot conditions, and difficulty maintaining work output during very hot weather	Call to improve workers knowledge on extreme heat exposure and its health effect and health promotion strategies

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
Lundgren et al.	Systematic review (Pearl picking)	Mixed methods	Assessment on the effects of heat stress on working populations	Developing countries	Climate change impact and occupational heat strain on workers	Review of information climate change effect on vulnerable groups in developing countries	Urban heat island effect, physical work, individual difference can exacerbate heat stress on workers	Adoption of preventive and control measures to achieve multiple benefits
Moda and Alshahrani,	Survey-based quantitative case study	Univariate and bivariate analysis	Assessment of the relationship between temperatures and heat morbidi	Outdoor construction workers, Jizan	Extreme heat exposure and adaptation strategy	Assessment of adaptation strategy on workers response to extreme heat and	High rate of heat-induced injuries and illnesses and decrease of work productivity	Update on policy development around occupational heat stress and its risks within the region

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			ty among outdoor workers			its health impact		
Sett and Sahu,	Scenario based assessments	Univariate and bivariate analysis	Evaluation of workplace heat exposure, and productivity of female brickfield workers	Female brickfield workers -West Bengal, India	Heat exposure; and cardiac strain, workload; productivity	Heat stress exposure and work productivity impact	Encourage ergonomic interventions, rescheduling of the work rest cycle, frequent fluid intake	Not stated
Schulte and Chun,	Systematic review	Mixed methods	Development of a framework for the identification of	Working populations	Climate change effects and associated occupational hazards	Relationship between exposure to occupational hazards and	The use of sentinel effects and leading indicators to aid surveilla	Conceptual framework developed to aid decision makers to assess

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			climate change impact on work place, workers and occupational morbidity and mortality			incidence of morbidity, mortality and injury related to climate change impact	nce of climate related occupational effects	occupational health policy and recommendations
Moriok a et al. [27]	Cross-sectional study	Mixed method	Assessment of hot working environment at construction site in summer and health effect	Workers on site	Hot environment, outdoor work condition and associated health effect	Measurement of blood urea nitrogen, blood sugar, serum osmotic pressure and associated health effect	Preventive heat-stress measures such as adequate ventilation, palatable water and taking needed	Adaptation of administrative control-health education and training

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			on workers				rest needed to reduce heat stress	
Crowe et al.	Qualitative evaluation	Exploratory interviews	Assessment of heat-related health issues within the sugarcane industry	Sugarcane workers-	Climate change impact, heat stress, heat exposure and agriculture	Strategies for reducing heat-related health effects and impact measurement of workers productivities	Promote better understanding of the multiple factors drivers for the improvement of workers' health and safety	Not stated
Lucas et al.	Scenario based assessments	Not mentioned	Asses present and future ergonomic risk	Varied	Climate change, heat stress and occupati	Management of heat strain and reduce	Mandatory protection to occupational	Ensure clothing properties and thermoregulation

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			associated with working in extreme heat		onal injury	risk of serious ill health	heat to reduce impact of excessive heat exposure	are understood and managed appropriately
Hancock and Vasmatzidis,	Formative research	Not mentioned	Review of current knowledge state around the effect of heat stress on cognitive performance	Varied	Impact of heat stress on cognitive performance	Assessment of appropriate heat stress index to measure heat stress intensity in relation to cognitive work	The use of factors i.e., age gender, level of experience, motivation and training to better understand impact of heat stress on cognitive	Not stated

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
							performance	
Heavisside et al.	Scenario based assessments	Mixed methods	Review of health impacts associated with urban heat island through heat exposure	Varied	Estimations of the impacts of various climate change mitigation techniques and benefits to workers health and wellbeing	Quantitative estimate on UHI health impacts and measurement of UHI health mitigation measures	The need to highlight associated health risk climate change mitigation measures adaptation	Not stated
Numfan et al.	Case study	Mixed methods	Assess perception of climate change and	Supervisory personnel in government	Climate change perception and risk of occupati	Role of supervisors in the implementation	Association between workers level of educatio	Development of awareness and training on heat

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			occupational heat stress and adaptation strategies among mining workers	and private sectors, Ghana	onal heat stress and adaptation strategies	of occupational heat stress mitigation among mining workers	n and willingness to adopt control measures to mitigate against occupation heat stress linked to climate change	stress management among mining workers
Sorensen et al.	Narrative	Not mentioned	Case for polices to move beyond traditional separations and advancement of gender-	Varied	Integration of gender-based awareness in climate change intervention strategies	Plans and policies shift to reduce gender-based bias in the implementation of	Women's health outcome and economic prosperity as surrogate markers for	Improve reporting mechanism based on common indicators

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			based solution			climate change adaptation strategies	policies and projects aimed at reduction in disaster risk and climate change adaptation	
Flocks et al.	Community based participatory	Thematic analysis	Assess work practices, individual risk factors and physiological response of female workers in hot	Hispanic and Haitian nursery and fernery workers in Florida	Beliefs, perception and health related illness and pregnancy health	Awareness of heat related health effects on pregnancy and fetal health	Measure to better address heat as specific occupational hazard among women and pregnancy health	Not stated

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			environments					
Varghese et al.	Systematic review	Thematic analysis	Assessment of the relationship between heat exposure and occupational injuries	Varied	Climate change, health and safety and workplace heat exposure	Impact of workplace heat exposure and occupational injuries	The need for an increased awareness of injury risk during hot weather and the economic benefits associated with averting injury, poor health outcomes and lost	Investigate specific injuries and the workers at risk due to workplace heat exposure

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
							productivity	
Kjellstrom et al.	Ecological design	Narrative	Assessment of special risk, health risk policies and strategies in the South-East Asia Region	South East – Asia regions	Threat to occupational health and productivity in South East Asia regions	Reduction of greenhouse gases from sources beyond current national plans	Adoption of effective prevention of workplace heat stress	National analysis and report on climate change impact
Acharya et al.	Scoping review	Mixed methods	Assessment of the severity with which construction workers are	Varied	Climate change, heat related illness among construction workers	Review heat-related Illnesses risk among construction workers	Knowledge gap around heat related health effects among construction	Assessment of construction workers exposure–response associations under a large

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			affected by heat stress, risk factors and co-morbidities associated with heat-related illnesses		and heat stress		workers despite the in global temperatures	range of temperatures and across locations and development of effective intervention and prevention action plans
Numfan et al.	Systematic review	Mixed methods	Review of climate change risks and heat stress exposure on employees health	Varied	Awareness of occupational heat stress, social impacts and adaptation strategies	Workers awareness and adaptation strategy to occupational heat stress exposure	Adaptation strategies key for policy development aim at improving occupational	Improve policies around occupational stress management

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			and safety, productivity and social well-being				heat stress	
Kjellstrom et al.	Scenario based assessments	Mixed methods approach	Assessment of physiological as indicative measures of reduced wok capacity and human performance due to heat increase	Indoor and outdoor workforce in tropical and subtropical regions	Review of Climate change impact, productivity and socioeconomic impact	Prevention of clinical damage to organs function and diminished human performance capacity due to climate change	Social and economic impact due to climate change	Climate change related occupational health impact assessment

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
Kjellstrom et al.	Case series	Triangulation method	Assessment of climate change extent on labour productivity due to increased temperature and humidity under future projections	Workforce in different world region and climate types	Assessment of Climate change impact and labour productivity	Climate change adaptation measure and its impact on human systems	Adaptation measures between high income nation and low income counterpart may varies	Climate change impacts and adaptation strategies at local and country level
Kjellstrom et al.	Scenario based assessments	Formative methods	Introduction of occupational heat stress index and	Workers in low and middle income tropical countries	Heat exposure impact on productivity and occupati	Adaptation measures in low and middle income countrie	Need for effective preventive measure to reduce occupati	Adoption of appropriate preventive measures in

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			how workers are likely to be affected by different level of heat exposure		onal health	s outdoor workers	onal heat stress and reduce the burden on socioeconomic development	planning process for work environment and urban development
Al-Bouwarthan et al.	Scenario based assessments	Mixed methods	Assessment of work factors related to heat stress exposure among construction workers	Construction workers –Saudi Arabia	Extreme heat exposure, climate change impact and construction workers	Development of occupational heat exposure guidelines	Call for assessment of both short and long term health impacts due to prolong heat exposure	Develop threshold based on heat index/WBGT for heat stress risk at work

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
Hanna et al.	Scenario based assessments	Not mentioned	Examine the emerging risk for working people and review of national occupational health and safety policy	Working population	Heat exposure and adaption	Review of public health policy	Health risk associated with heat exposure among workers	Climate change adaptation and Occupational health and safety guidelines
Ylipaa et al.	Qualitative research design	Not mentioned	Assessment of impacts and vulnerabilities of workers to	Varied: Agriculture workers	Climate change adaptation; gender inequality; feminist	The need for inclusive and Situation-Based climate change adaptati	Gender-informed climate change adaptation that acknowledges	Call for recognition of social relations and location, in national

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			climate change		political ecology	on policies	important conditions	strategies and policies to support national targets on climate response, gender equality, and sustainable development
Ward et al.	Case study	Spatial comparison, Univariate and bivariate analysis	Investigate causes of surface urban heat island and impact of urban	European cities with different climate zone and population density	Surface heat island magnitude and heat waves	Introduction of heat magnitude to assess added heat load during heat waves	Case specific adaptation strategies for urban planning	Development of heat stress risk evaluation measures

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			pattern and land use characteristics					
Leal Filho et al.	Narrative review	Mixed method	To improve the knowledge basis of urban heat islands and the scale of vulnerability	Two regions: Germany and Australia	Urban heat island vulnerability cities and climate change mitigation and adaptation	Mitigating the impacts of urban heat islands	Increased vulnerability of cities to the negative impacts of urban heat	Urban heat island mitigation and adaptation strategies which take the particularities of each community into account
Xiang et al.	Systematic review	Thematic analysis	Review of workplace heat exposure	Varied: farmers, construction workers, fire-	Work related injury, heat exposure and	Effect of workplace heat exposure due to climate	Potential impacts of workplace heat	Not stated

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			characteristics in high risk occupations	fighters, miners, soldiers, and manufacturing workers	climate change	change and work related injury	exposure are underestimated as a result of underreporting of heat related illnesses	
Chersich and Wright,	Systematic review	Thematic analysis	Assessment of climate change adaptation policy frameworks and review of preparedness levels and	South African health sector	Climate change adaptation, extreme weather, health systems, health policy	Climate change adaptation policy and extreme weather preparedness level	Climate change adaptation policy status and level preparedness against extreme conditions	Effective use of data, strengthening of the health profession, increased health sector leadership

Author and Year	Study Design	Analysis Methods	Study Aim	Study Populations	Study Theme	Study Intervention	Outcome Data	Outcome Measure
			action around extreme weather events					
Sheng et al.	Case-crossover study	Stratified case-crossover method	Association between high temperature exposure and work related injury	Working groups, Guangzhou	Relationship between extreme temperature and work related injury	Associated injury risk at work due to hot weather conditions	Estimation of future impacts of climate change on workers and adaptation strategies	Not stated

Chapter 4

Results and Discussion

Based on the period selected (2002–2019) for the included studies, 22 (68.8%) of them were published between 2014 and 2019. Of the 32 papers analyzed, four papers (12.5%) directly considered the impacts of climate change on workers' health in different countries (Ghana, South Africa, Saudi Arabia, Germany, Australia, USA, Italy, India). Four (12.5%) of the papers considered the impacts of climate change, workplace heat exposure and heat stress among female workers. Seven (21.9%) of the papers focused on climate change, workplace heat exposure, heat stress, etc. within the construction industry. Overall, the trends of topics identified from the papers considered include the influence of climate change and heat stress, workplace injury and work productivity.

From the data abstraction undertaken based on keywords adopted; 32 studies selected were grouped into five major themes. This was also done based on their similarities, emerging patterns and differences. The themes that emerged, based on the study categories, include:

(a)Climate change impacts on outdoor workers safety and health;

(b)Urban Heat Island (UHI) and Occupational Health Impacts on Outdoor Workers;

(c)Heat stress and outdoor workers performance;

(d)Occupational health hazards and effects related to climate change;

(e)Adaptation of workers to occupational heat stress.

Among the included studies, the impacts of climate change on workers' health was the major commonality while their major differences were around the interventions considered. Broad findings from the studies revealed that exposure to extreme heat due to climate change is associated with negative health impacts and possible decreases in productivity. In addition, the need for

sentinel effects and leading indicators to aid surveillance of climate related occupational effects have also been highlighted in several of the studies. Different study designs were adopted among the studies considered, while a mixed method approach was adopted as the analysis method by 44% of the studies.

3.1. Climate Change Impacts on Construction Workers' Safety

At the turn of the century, urban areas (especially in underdeveloped and developing countries such as those in sub-Saharan Africa) witnessed a sudden surge of movement from rural settlements into urban areas in search of better living conditions. This trend has resulted in greater pressures to the urban environment, especially considering that around 40% of the population in the African continent are now living in and around urban settlements, as reported by the World Bank. In addition, the migration process has been supported by the diversity of economic and social opportunities available in these urban settlements within the African Continent. Temperatures across the African continent are expected to increase faster than the global average, while mean annual precipitation is projected to decrease in and around the Mediterranean and Northern and Southern parts of the continent. However, precipitation in the Western part of the continent will vary. Further to this, the near surface temperatures in most parts of Africa has seen an increased temperature rise of 0.5 °C or more in the last century, with minimum temperatures warming more rapidly than maximum temperatures. These trends may have been influenced by other components of natural variability and human activity.

To understand the impacts caused by climate change, there is first the need to understand the phenomenon itself. The availability of manmade heat absorbing features such as concrete buildings, surface modification, pollution generated from automobiles etc. in urban areas has helped increase heat absorption during the day, and its gradual release back into the atmosphere at nighttime. This has had an impact on temperature differences between urban and rural areas, and sped up the urban heat island (UHI) phenomenon in urban areas. Another contributory factor to the UHI effect is the absence of moisture in urban areas and increased anthropogenic heating. This increase has been shown to have direct significant effects on outdoor workers' thermal comfort, higher energy usage and air quality, with detrimental health effects and possible mortality increase.

The indirect impacts resulting from unsustainable consumption, such as pollution increase and waste generation, are also seen in these areas. In addition, changes in land use and land cover in urban areas has influenced the urban climate and is leading to an increase in temperature. There is now a need for evidence-based studies on climate change adaptation and urban heat island effects in relation to outdoor workers. This can raise awareness of occupational health hazards in

order to establish risk awareness and coping strategies among workers, managers, and other stakeholders .While there is anecdotal evidence based on research carried out in other parts of the world regarding excessive heat exposure and its impact on workers' health, safety, productivity and workplace environmental conditions and adaptation strategies, there is a paucity of similar data among outdoor workers in parts of sub-Saharan Africa; especially in a changing climate as perceived today

Diurnal Variation of Temperature

The day temperatures show a diurnal variation of about 10 to 12 degree C during the season. Figure 4 shows the diurnal variation of temperature over Lucknow during the first and second fortnights of December, January and February. Lowest temperatures are recorded around 07 hours IST during the season. A steep rise is experienced from 0800 hours IST to 1200 hours IST. However they continue to rise till 1600 hrs IST. The temperatures are lower by about 3 to 5 degrees at all hours of the day during the coldest month of January than those recorded in the second fortnight of February

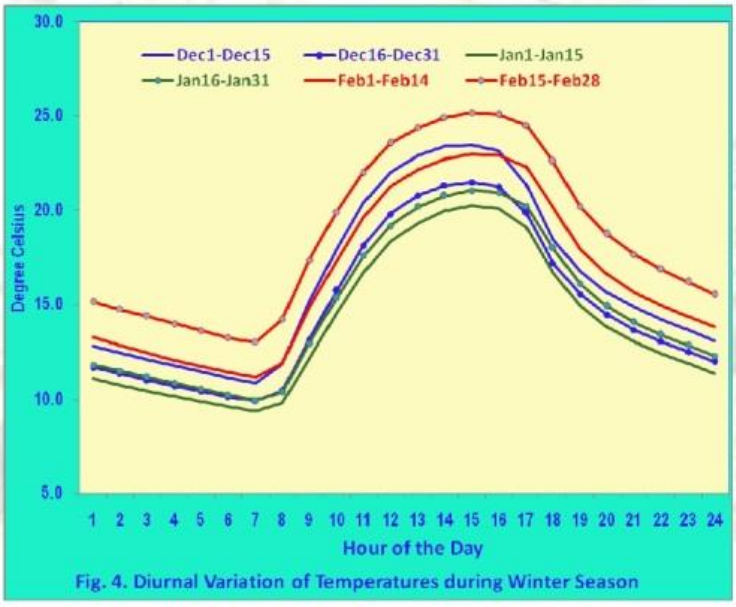


Fig. 4. Diurnal Variation of Temperatures during Winter Season

Extreme Temperatures

The highest and lowest maximum temperatures recorded during the season (1971-2010) given below show that maximum temperatures can have quite a large range during the season. The highest maximum temperatures in the month of December range around 26 to 29 Deg C during most of the years. They range around 25 to 30 Deg C during January and 30 Deg. C to 35 deg C during February. The highest maximum temperatures recorded during the period are 29.9 Deg C for December(4 December, 1976), 31.6 Deg. C for January (4 January, 1992) and 35.9 Deg C for February (25 February, 2006). The lowest maximum temperatures recorded in the city for different months during the season are 11.0 Deg. C for December (2 December, 2003) 10.2 Deg. C for January (17 January, 2003) and 14.5 Deg. C or February (1 February, 1982).

The maximum temperatures on certain days remain very much below normal due to persistent fog and cold winds leading to cold day conditions (when maximum temperature is 16^0 C or below). Foggy conditions prevail during winter for several days or weeks leading to above normal minimum temperatures and below normal maximum temperatures. The average number of cold days in 0.55 for December, 2.0 for January and negligible (0.05) for February. However, there is large inter-annual variation. The highest number of cold days were 6 for December (1997) and 19 days for January (2003).

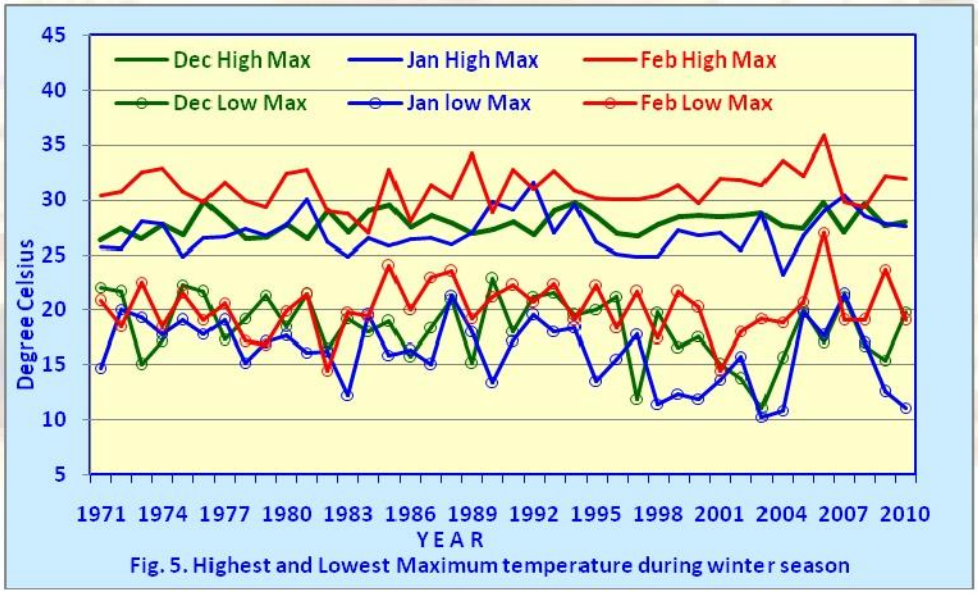


Fig. 5. Highest and Lowest Maximum temperature during winter season

During most of the years, The lowest minimum temperatures recorded are around 4-6 Deg . C during December , around 3-5 Deg . C during January and around 6-8 Deg C during February (Fig .6.). However, quite low temperatures have been recorded in some of the years for all three months. The all time record for lowest minimum temperature during the season are 0.5 Deg. C on December 31, 1973, -1.0 Deg. C on 31st January 1964, 0.0 Deg. C in 2nd February, 1964.

Such low temperatures are recorded when cold northerly winds from the frigid Eurasion land mass set in over the area after the passage of a western disturbance across northern parts of the country. The minimum temperatures can be quite high (14 to 16 Deg C) on an individual days during the season, particularly ahead of an approaching western disturbance, when moist air from south penetrates into the region and nights are cloudy allowing little nocturnal cooling. The highest minimum temperatures recorded in the city for various months during the season are 17.3 Deg. C on 25 December, 1980, 15.5 Deg. C in 31 January, 2005, 19.6 in 25 February, 1999.

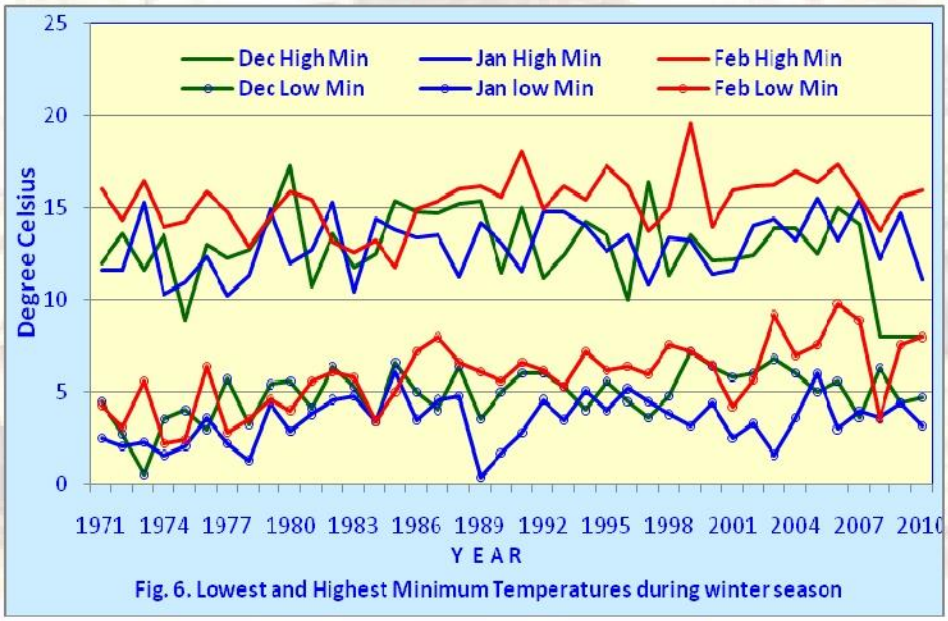


Fig. 6. Lowest and Highest Minimum Temperatures during winter season

The rise in temperature on the approach of western disturbances is a relatively slow process whereas the fall is steeper as they move away. These rise/fall are because of the change in the air mass on approach and in the rear of these disturbances. The highest fall in the maximum and minimum temperature are given in table 5. The maximum temperature recorded on 02 January 1992 was 11.5 ^{0}C lower than that of previous day. Also the night of 14 February 1972 was 9.2^{0}C cooler than that of 13 February 1972.

The probability of minimum temperatures to fall below 5 and 10 Deg. Given in Fig. 7. Show very high probability (60%) of minimum temperatures to fall below 10 deg. C from third week of December to third week of January it goes down to below 35% from middle of February. The probability of minimum temperatures to fall below 5 deg. C is around less than 5% from in the second fortnight of December and its probability is maximum in first and the third week of January. It is negligible till 15 December in the beginning and in the month of February.

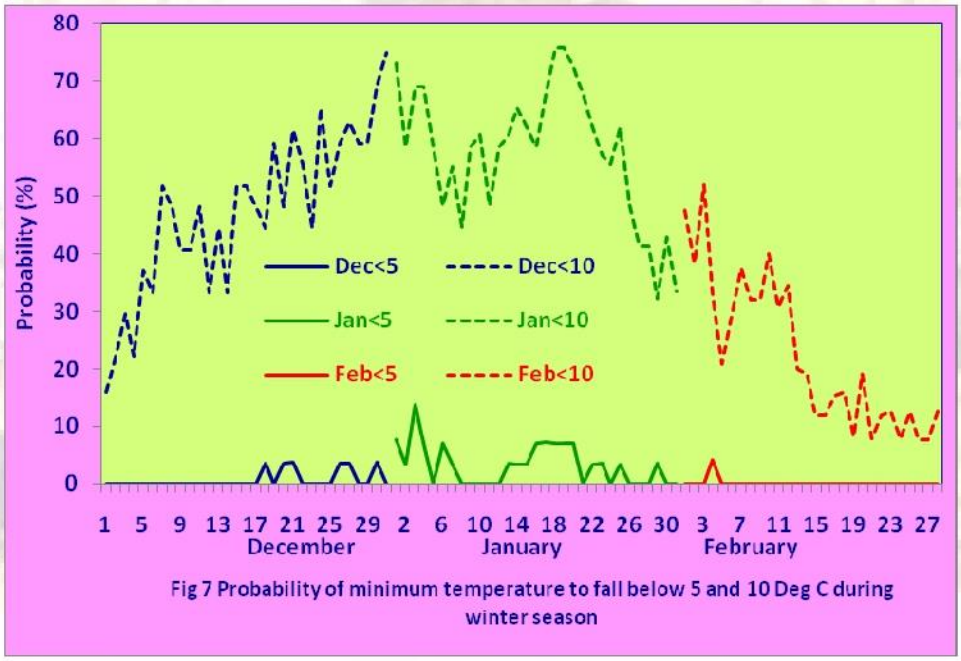


Fig 7 Probability of minimum temperature to fall below 5 and 10 Deg C during winter season

Diurnal Variation of Relative Humidity

The diurnal variation of RH (Fig. 9) shows that the highest RH of about 85-90 % is recorded at 0800 hrs IST during most of the season except for second fortnight of February when the maximum RH of about 80% is recorded at 0700 hrs IST. It shows a sharp decline from 0800 to 1300 hrs IST with a gradual fall afterwards till 1600 hrs IST. It then register a sharp increase reaching to 2200 hours in the night during most of the season except in February when it reaches up t0 70-75%. The RH is highest during second half of December and first half of January at all hours of the day and the lowest in the second half of February.

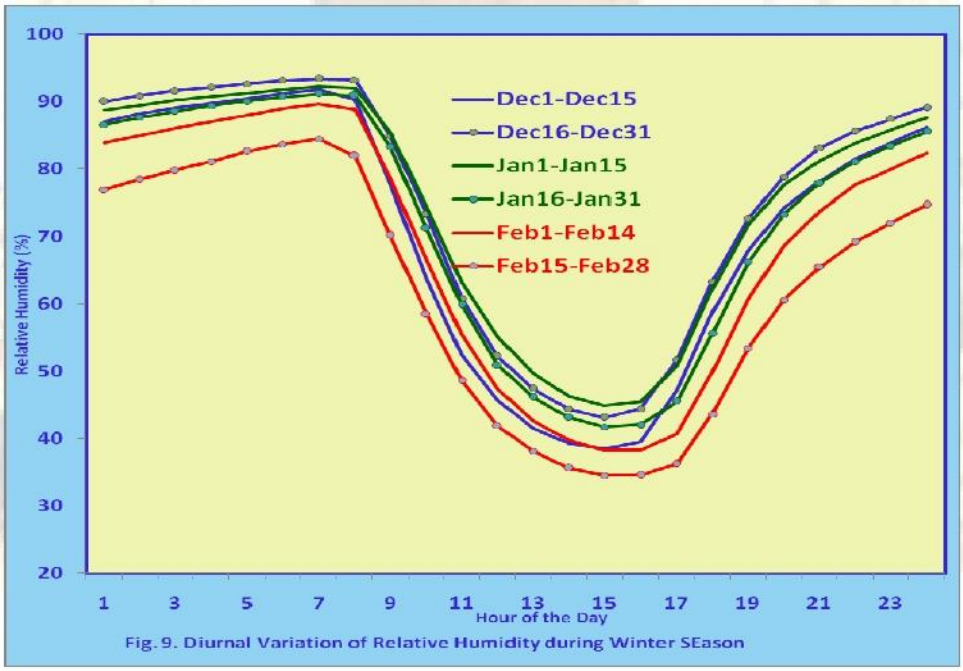


Fig. 9. Diurnal Variation of Relative Humidity during Winter SEason

Heavy Rains

Heavy rains are normally not experienced during winter season except one or two cases when exceptionally heavy rainfall recorded at the station. The heaviest 24 hours rainfall of winter months (1971-2010) in Figure 12 shows that 2-3 cm in 24 hours is not uncommon during the Season. The Heaviest rainfall (1971-2010) in 24 hours for the months of December, January and February are 46.2 mm (9 December, 1997), 65.0 mm (2 January, 1980), 46.7 mm (1 February, 1982), respectively.

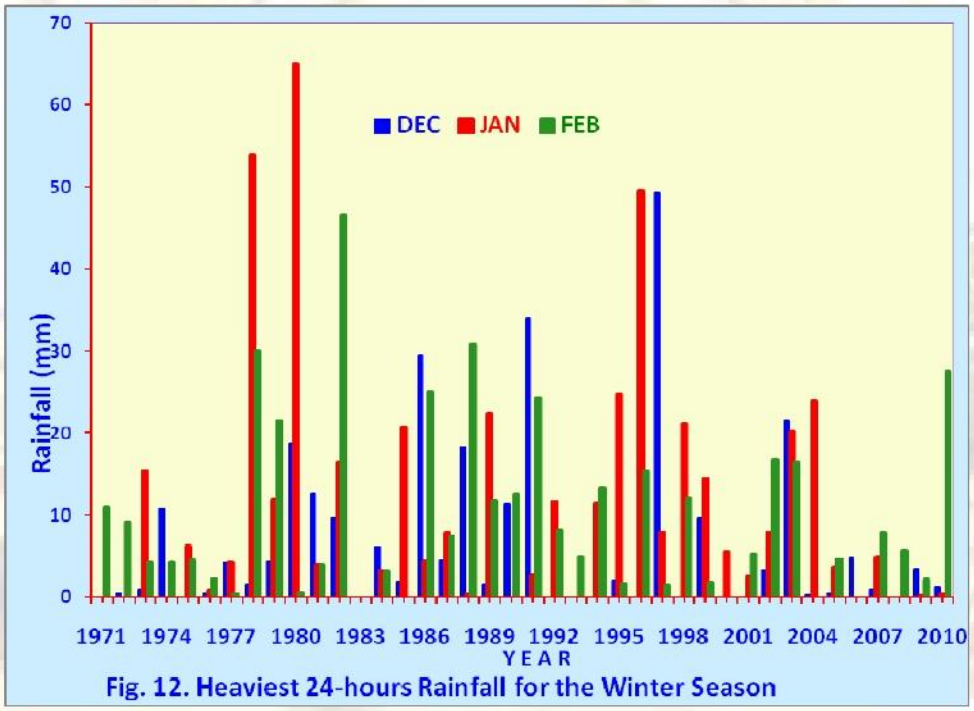
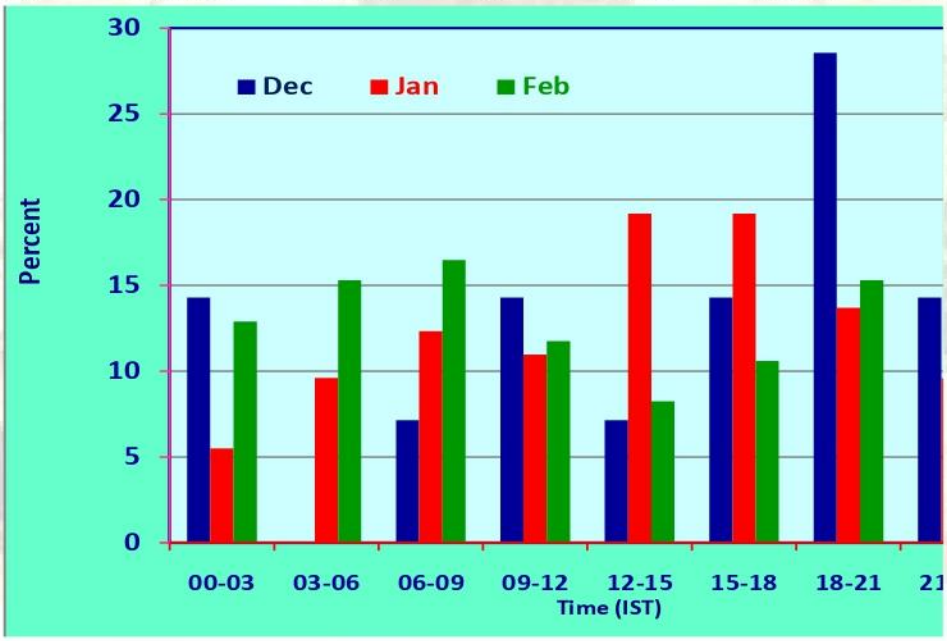


Fig. 12. Heaviest 24-hours Rainfall for the Winter Season

Thunderstorm and other weather phenomena

Thunderstorm activity is not very high during the season with an average of only 0.6, 0.9 and 2.2 days of thunderstorm during December, January and February respectively. However there is large inter-annual variation in number of days with thunderstorm ranging from zero during many years to maximum of 3 In December (1991), 7 in January (1983 & 1999) and 6 In February (1990 & 2005). The diurnal variation of thunderstorms (Figure 13) shows that the most preferred time is from 1800-2100 hrs in the month of December, during which more than 29% thunderstorms occurred , 1200-1800 in the month of January occurring more than 38% thunderstorms during the period and from 0300 to 0900 hrs in the month of February occurring 32% thunderstorms during the period. Other phenomena, except for fog, are not very common during the season (Table. 4)



3.2. Urban Heat Island (UHI) and Occupational Health Impacts on Outdoor Workers

An urban heat island (UHI) is an urban area that exhibits higher temperatures compared to the rural or suburban surroundings. The UHI effect is due to various factors, such as air pollution, anthropogenic heat, urban architecture and variations in precipitation patterns. The UHI impacts on human health through the exposure to increased temperatures and can be problematic specifically during heat waves. While the UHI effect affects the public in general, there is also the need for attention to the effects it poses on the health of workers specifically. Heat exposure has been previously linked to various adverse health effects, from the aggravation of minor conditions such as general discomfort, heat cramps, respiratory difficulties, heat stroke to increased chances of hospitalization and even death.

Health impacts from UHI are more severe during the summertime, the season of immensely high temperature or heat waves. Thus, heat-related mortality is likely to increase in future due to climate change. Heat mortality may occur due to the overloading of the cardiovascular and respiratory systems, as physiological reactions to heat exposure. The physiological reactions that take place are increased heart rate, increased body temperature, increased sweating, fluctuation of blood flow towards the skin from the central organs, and dehydration. The Urban Heat Island is also a nocturnal phenomenon, resulting in increased temperature at night due to the release of heat. This increased temperature causes a lack of relief at night and prevents the body from recovering from the heat exposure experienced during the day.

The UHI phenomenon can lead to an increase in energy consumption due to the demand for more use of cooling devices, thus increasing the overall electricity use. The companies which supply the electricity rely on power plants which typically use fossil fuels to meet the required demand, which results in the release of air pollutants and emission of greenhouse gases. These gases include Sulphur dioxide, nitrogen oxides, carbon monoxide, among others, all of which negatively impact air quality and contribute to ground-level ozone formation, particulate matter generation and acid rain. The elderly population, minors and those with existing heart conditions are most likely to be

affected by these effects. Increases in wind speed may help to reduce the severity of but only to a limited extent.

Along with climate change, the impact of heat in the urban area will increase in the future. People working in hot weather involving heavy physical activity without appropriate protection are at increased risk of suffering from heat-related health effects. In the urban inner cities, the major effect of UHI is human discomfort which is well documented in previous urban heat stress studies. The UHI effect increases the temperature in cities exposing the urban population to more heat stress compared to rural areas. In August 2003, during two weeks of extreme heat more than 1000 deaths and several associated illnesses of people aged 20–70 occurred in France which greatly impacted the nations working group.

The 'heat island effect' is partly responsible for the current changes in temperature in many cities. People working outdoors (such as traffic wardens, fire fighters, road sweepers, landscapers' petty traders, construction workers etc.), during the hottest periods face an additional 3–5 °C increase in temperature which will make heavy work very challenging. When working in a hot environment, workers (including healthy ones) are under tremendous strain. Their sweating (body's cooling mechanism) efficacy is reduced due to limited air movement towards the skin. In addition, the protective clothing used by workers which protects them from exposure to chemicals, trauma, and other pollutants, may hinder evaporative heat loss, further reducing the sweating efficacy. Another factor that may increase UHI is the inadequate intake of water which results in dehydration, and therefore reduces sweating and resultant heat loss. Dehydration also contributes to impairment of mental and physical performance.

There is a strong relationship between the UHI effect and urban planning. This is due to the fact that the absence of trees and vegetation in urban areas affects the transpiration process. The implementation of proper vegetation in urban areas helps cool the surroundings, resulting in increased evapotranspiration and reducing the UHI effect. Other measures include the use of water bodies to reduce thermal load and decreasing the anthropogenic heat. lists some examples of health impacts of UHI on outdoor workers.

Table 3

Health Impacts of Urban Heat Island (UHI) on Outdoor Workers.

Health Impacts	**Author & Year**
Heat exposure Heat Stress/Stroke Fatigue Dehydration and Kidney Disease Cardiovascular Disease Respiratory Distress Death Increase morbidity and fatality	Leal Filho et al. Ward et al. Kjellstrom et al Heaviside et al Hanna et al Tan et al Kovats and Hajat,
Air Pollution Respiratory Distress Respiratory Track Irritation Asthma Attack Increased Respiration due to Heat exposure Exposure to carcinogens	Kjellstrom et al. Ward et al. Kjellstrom et al.
Unbalanced Physiological Function leading to decrease in work capacity	Lucas et al. Lundgren et al. Kjellstrom et al. Kovats and Hajat,
Extreme weather and sea level rise High risk of flooding causing displacement Injury Resource disruption e.g., water supply	Kjellstrom et al. McGranahan et al.
Psychological effects on Workers Mental health	Kjellstrom et al. Lundgren et al.

Health Impacts	Author & Year
	Hanna et al. Kjellstrom et al.

3.3. Heat Stress and the Performance of Outdoor Workers

While individuals are in general capable of acclimatizing to different levels of heat, it is worth noting that every worker also has an upper limit to heat exposure, stress beyond which will become unbearable and may cause health related ailments and—in extreme cases—can lead to mortality. Understandably, there is limited, or no adaptation measures considered for outdoor workers involved with constant physical labor and working in humid conditions. There is an increased likelihood of these workers experiencing heat stress, which could lead to reduced work performance and capacity, with potentially significant economic consequences. Wherever the ambient temperature exceeds 35 °C, there is a greater chance of it causing fatigue and physical exhaustion among workers in general. There is also an increased risk of errors, which could be catastrophic, especially where concentration is required for the safe handling and operation of machinery. Outdoor women worker's health is another problem that has drawn attention recently; in particular, during pregnancy as it creates additional heat stress problems. Respiratory and cardiovascular disease, secondary to exposure to poor air quality, has been found to have a larger impact on women because of their greater propensity for higher deposition of particulate matter in lung tissue. In general, outdoor workers are faced with elevated risks of heat-related illnesses (HRI). However, pregnant women exposed to extreme heat are faced with additional health risks, including poor pregnancy health and birth outcomes, as highlighted in earlier reports [This calls for empowering women through provision of education and awareness as a means of improving mitigation and mitigation policy intervention.

As earlier mentioned by Kjellstrom et al., there are two pathways that extreme heat exposure impacts could manifest in workers. Both physiological and psychological tasks and heat balance within the human body are determined by six fundamental factors that include; air temperature; radiant temperature; humidity; air movement (wind speed); clothing; and the metabolic heat generated by human physical activity. As such, perceptual awareness alongside the control over

work conditions, work rates, and work limits are immediate adaptation mechanisms against heat exposure among individual workers. To address the physiological impact caused by heat exposure, several heat stress indices have been developed. These have been developed in order to help in the prediction of physiological strain experienced among workers due to exposure to stressful environmental conditions The use of indexes provides information between climate parameters (air temperature, air humidity, air movement over the skin (wind speed) and heat radiation (i.e., from the sun)) which can then be linked to a corresponding physiological strain. The results of these indices can be used in the design or establishment of safe work practices, work limits and work conditions. Wet Bulb Globe Temperature (WBGT) was developed by the US Army in the 1950s to help reduce exposure to excess heat. WBGT is now the most widely used tool for occupational heat stress assessment. It takes into consideration four environmental factors; air temperature, relative humidity, wind speed, and radiation. However, clothing type, activity and acclimatization can significantly impact on the adaptation strategy adopted by the individual, despite the use of WBGT to quantify heat stress tolerance. As such, the interpretation of the WBGT value requires these factors to be taken into account.

Guidelines for the application of WBGT on occupational heat exposure recommend maximum heat exposures for jobs with various work intensities. They also need to account for the number of work hours after which a worker will be required to take a break to avoid the core body temperature exceeding 37 °C . Reference to WBGT ‘reference values’, (the point at which some preventive action should be taken) as developed by the international standard, provide further guidance on the different levels of work where workers will need hourly rests, or rests of 25, 50 and 75% (rest/work ratios).

3.4. Occupational Health Hazards and Effects Related to Climate Change

There are links between prevailing climatic factors and occupational health hazards that can be associated to climate change. Likely hazards due to climate change and their effects on vulnerable outdoor groups, as well as aliments associated with occupational exposure to excessive heat have been identified. These include; heat-associated self-reported nausea or vomiting, painful muscular

spasms, confusion, dizziness, or fainting, hot dry skin and self-reported heat strain according to previous studies.

Outdoor workers in certain occupational sectors such as agriculture, construction, transportation, utility maintenance, oil production, firefighting and other emergency services are usually among the first to experience the effects of climate change. These are exacerbated in most instances by the need to wear protective clothing, which can lead to heat stress. In addition, such effects could have a far-reaching impact on their health and the nation's economy. Excessive environmental heat is seen as the most frequent climate change impact and as such, with prolonged hot weather, outdoor workers health in sub-Saharan African countries, are at risk from heat-related outcomes (Table 1).

Where these workers are exposed to a higher temperature than 37 °C, for their body to stay at a healthy temperature they will have to lose this excessive heat through sweat evaporation. However, as earlier reported high external air humidity and clothing type were identified as limitations sweat evaporation and regulation of body temperature. Therefore, to avoid heat stroke workers will need to reduce their work rate, take more rest, and rehydrate. However, Moda and Alshahrani reported that outdoor workers on construction sites in Saudi Arabia described the lack of palatable water as a key set back to their water intake and rehydration. This is often caused by the portable water provision on site becoming warm during the day due to lack of a cooler, thus leaving the workers dehydrated, exhausted and at some point, experiencing severe fatigue among other symptoms reported. In addition, heat stress and fatigue suffered by these workers negatively impacted their levels of alertness and work capacity. This led to the frequent occurrence of safety lapses leading to a high risk of injury at work. Most workplaces in developing countries do not have a heat stress index on site, therefore workers rely on environmental temperature references from the weather station for the city, as reported by Moda and Alshahrani. Unfortunately, the immediate local ambient temperature could vary from that reported by the weather station and the workers might be exposed to a more extreme temperature than reported.

Apart from the effects of extreme heat, a higher temperature can lead to increased ground-level ozone and fine particulate matter air pollution, thereby increasing the risk of cardiopulmonary

dysfunction, reduced lung function and other respiratory illnesses (Table 3). These other effects also increase the level of carbon dioxide in the air and promote plant growth and the release of airborne allergens, which could increase allergic reaction and asthma episodes among vulnerable groups. To help visualize climate change impacts and related occupational safety and health issues, Schulte and Chun developed a conceptual framework. This framework highlights the impact climate change is likely to have on the workplace among different workers, including occupational morbidity, mortality, and injury as influenced by several driving and contextual factors. The likely hazards that will occur in different settings may include increased ambient temperature; air pollution; ultraviolet (UV) radiation; extreme weather; expanded vector habitats; industrial transitions and emerging industries; and changes in the built environment.

Release and exposure to environmental chemicals due to increased heat is expected to increase through various routes. These include increased pesticide use, changes in transport pathways such as dust proliferation, increased chemical dispersal from storm runoff, and increases in chemical spills from floods and fires. Several workers in trades or industries using or producing petroleum products (such as coal etc.), and those working in close proximity where the combustion of these products occur (such as traffic wardens, taxi/bus drivers, road maintenance etc.) are vulnerable to polycyclic aromatic hydrocarbon (PAH) exposure. However, their impact due to climate change are said to vary. In addition to this, the presence and exposure of legacy pollutants (persistent substances like DDT, dioxins, PCBs, mercury, etc.) that have accumulated in environmental reservoirs (such as surface soils, sediments, and forests), especially among workers in certain occupations, could be influenced by climate change . These pollutants impact health, including, but not limited to, cancer, adverse reproductive outcomes, impaired neurodevelopment, and disruption of the endocrine and immune systems .

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Adapted and modified from Applebaum et al.and Kjellstrom et al.

In addition, workers in areas with poor water drainage management and areas that encourage vector breeding are affected by extreme climate events. This is especially concerning considering that some of these vector borne diseases i.e., yellow fever, malaria, dengue and chikungunya are

sensitive to climatic changes and likely to expand in geographic zones and affect a diverse range of worker populations . The burdens associated with vector borne diseases tend to be much higher in developing countries. For instance, the per capita mortality rate from vector-borne diseases is projected to be 300 times greater in developing nations than in developed regions. This is due in part to their prevalence in the tropical regions and low socioeconomic development, which has a negative impact on the quality of health care services delivered.

3.5. Adaptation of Workers to Occupational Heat Stress: Some Research Priorities

There is the need for occupational climate change policies be considered at a micro level, especially since adaptive capacity may vary between groups, communities, and individuals and will rely on the vulnerability level, resilience, and resource availability as the global temperature continues to rise. Heat stress exposure and associated health effects cannot be ignored in the workplace, especially in sub-Saharan Africa where climate change is more pronounced. On this note, it is imperative that climate change adaptation be considered at various workplace levels and is not a collectivist approach, which does not take into account the diverse needs of the varying workers.

The intergovernmental Panel on Climate Change (IPPC) affirmed that if the present climate change trend persists, by the middle of the century, high temperatures and humidity would probably compromise outdoor working. Thus, leading to lost work capacity and reduced labor productivity among vulnerable populations, such as that in sub-Saharan Africa, and will eventually cause economic loss. To avoid productivity and economic loss and social ramifications resulting from extreme heat exposure among outdoor workers, there is a need for employers to consider measures capable of protecting workers and their businesses through investment into appropriate climate change adaptation measures. Historically, individuals working under extreme climate have tried different measures aimed at adapting to their work conditions. They include, working with light cloth, dousing themselves with water to regulate their internal body temperature, consumption of water, taking intermittent breaks etc., however, these techniques require further scientific measures

aimed at complementing these tools, especially where it is insufficient for coping with extreme hot weather conditions.

Key research priorities need to meet this challenge. It is firstly important to investigate effective adaptation measures to ensure workers involved in heavy labour are not faced with an increased risk of heat stress, which could affect their health, work performance and work capacity. Further to this, there is also a need to consider the right adaptation strategy among workers when developing occupational guidelines. These guides should take into account several factors likely to play a role in climate change and heat exposure, which could affect the individual's sensitivity to heat tolerance. In addition, there is also a need to consider intervention strategies around workers coping mechanisms, including adaptation and social protection measures when designing engineering solutions. Furthermore, research on the role of administrative controls along with studies on how to enhance education and awareness on the management of climate change and heat exposure among workers in general is considered timely, especially in Africa. There is also the need to ensure the establishment of a platform capable of overcoming barriers to climate change adaptation and heat stress risk which takes into consideration resource availability and technological advancements in tropical regions.

Chapter 5

4. Conclusion

From the studies considered, it is evident that the frequency and intensity of extreme hot weather conditions due to climate change, extreme workplace heat exposure and the abatement of workplace ill health and injury will continue to present challenges, in the developing countries located in the tropics, and the globe at large, especially in fast-paced work environments. To date, most studies on climate change impacts and health have focused on the general public's health. Limited documented evidence exists on climate change impact on occupational health and safety among outdoor workers, especially in developing countries in sub-Saharan Africa where its impact is mostly felt. While approaches are considered for the protection of workers from extreme heat exposure due to climate change, there is also the need for the development of appropriate surveillance programmes, thus enabling the proper assessment of occupational heat exposure and related injury and illness because of climate change extremes within different occupational sectors.

As a result of paucity of up to date data on outdoor workplace heat exposure, workplace climate change adaptation strategies and other relevant related health and safety issues, the assessment of impacts of climate change and how it affects workers in the tropical countries such as Africa is considered timely. This includes the need for current information on the effective management of climate change impacts. In addition, gender response to climate change impacts on the continent workforce will require the development of more evidence, where a high proportion of women now work in fast-paced outdoor industries that include agriculture, mining and construction. To strengthen the knowledge of climate change, workplace heat exposure and related workplace injury and to guide safety adaptation measures, there is a need for multidisciplinary research to help in the quantification and forecast of workers hazards exposure by occupation and location in these countries where the impact of climate change is more pronounced. Research areas proposed in the assessment of climate change impacts on outdoor workers productivity and occupational safety include:

i. Assessment of climate change impacts among vulnerable outdoor workers; such as pregnant women, children elderly in the continent
ii. Occupational heat stress and adaptation of sustainable measures
iii. Association between heat stress exposure and response under varied working conditions
iv. Assessment of combined effects associated with heat stress and other related environmental and physical stressors
v. Development of micro adaptation alternatives to tackle workplace climate change challenges

To measure the occupational illness and injury burden among outdoor workers, research that considers the relationship between socioeconomic status and other relevant indicators that affect climate change, and occupational safety and health of these workers is further advocated for. Another area of study that needs looking at is the interplay between climate change, occupational hazards, and workers vulnerability. This is needed in order to help with the development of suitable climate change adaptation and risk management initiatives.

To conclude, climate change policy needs to take into consideration that at each micro level adaptive capacity may vary between groups, communities, and individuals and will rely on the vulnerability level, resilience, and resource availability. As such, there is a need to avoid a collectivist approach, as this approach does not acknowledge these differences.

References

1. Acharya P., Boggess B., Zhang K. Assessing Heat Stress and Health among Construction Workers in a Changing Climate: A Review. *Int. J. Environ. Res. Public Health.* 2018;**15**:247. doi: 10.3390/ijerph15020247. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
2. Al-Bouwarthan M., Quinn M.M., Kriebel D., Wegman D.H. Assessment of Heat Stress Exposure among Construction Workers in the Hot Desert Climate of Saudi Arabia. *Ann. Work. Expo. Health.* 2019;**63**:505–520. [PMC free article] [PubMed] [Google Scholar]
3. Applebaum K.M., Graham J., Gray G.M., Lapuma P., McCormick S.A., Northcross A., Perry M.J. An Overview of Occupational Risks from Climate Change. *Curr. Environ. Health Rep.* 2016;**3**:13–22. doi: 10.1007/s40572-016-0081-4. [PubMed] [CrossRef] [Google Scholar]
4. Balbus J.M., Boxall A.B., Fenske R.A., McKone T.E., Zeise L. Implications of global climate change for the assessment and management of human health risks of chemicals in the natural environment. *Environ. Toxicol. Chem.* 2013;**32**:62–78. doi: 10.1002/etc.2046. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
5. BS EN ISO 7243 . *Ergonomics of the Thermal Environment—Assessment of Heat Stress Using the WBGT (Wet Bulb Globe Temperature) Index (ISO 7243:2017)* International Organization for Standardization; Geneva, Switzerland: 2017. [Google Scholar]
6. Campbell-Lendrum D., Manga L., Bagayoko M., Sommerfeld J. Climate change and vector-borne diseases: What are the implications for public health research and policy? *Philos. Trans. R. Soc. B Boil. Sci.* 2015;**370**:20130552. doi: 10.1098/rstb.2013.0552. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

7. Chersich M.F., Wright C.Y. Climate change adaptation in South Africa: A case study on the role of the health sector. *Glob. Health.* 2019;**15** doi: 10.1186/s12992-019-0466-x. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
8. Crowe J., Joode B.V.W.D., Wesseling C. A pilot field evaluation on heat stress in sugarcane workers in Costa Rica: What to do next? *Glob. Health Action.* 2009;**2** doi: 10.3402/gha.v2i0.2062. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
9. EASAC European Academies' Science Advisory Council . *The Imperative of Climate Action to Protect Human Health in Europe.* EASAC European Academies' Science Advisory Council; Halle, Germany: 2019. EASAC Policy Report 28 June 2019. [Google Scholar]
10. EPA—United States Environmental Protection Agency Heat Island Impacts. [(accessed on 10 April 2019)];2014 Available online: https://www.epa.gov/heat-islands/heat-island-impacts.
11. Fang Y., Naik V., Horowitz L.W., Mauzerall D.L., Mauzerall D., Horowitz L. Air pollution and associated human mortality: The role of air pollutant emissions, climate change and methane concentration increases from the preindustrial period to present. *Atmospheric Chem. Phys. Discuss.* 2013;**13**:1377–1394. doi: 10.5194/acp-13-1377-2013. [CrossRef] [Google Scholar]
12. Fisk W.J. Review of some effects of climate change on indoor environmental quality and health and associated no-regrets mitigation measures. *Build. Environ.* 2015;**86**:70–80.
doi: 10.1016/j.buildenv.2014.12.024. [CrossRef] [Google Scholar]
13. Flocks J., Mac V.V.T., Runkle J., Tovar-Aguilar J.A., Economos J., McCauley L.A. Female Farmworkers' Perceptions of Heat-Related Illness and Pregnancy Health. *J. Agromed.* 2013;**18**:350–358. doi: 10.1080/1059924X.2013.826607. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
14. Flouris A.D., Dinas P.C., Ioannou L.G., Nybo L., Havenith G., Kenny G.P., Kjellstrom T. Workers' health and productivity under occupational heat strain: A

systematic review and meta-analysis. *Lancet Planet. Health.* 2018;**2**:e521–e531. doi: 10.1016/S2542-5196(18)30237-7. [PubMed] [CrossRef] [Google Scholar]

15. Gubernot D.M., Anderson G.B., Hunting K.L. The Epidemiology of Occupational Heat-Related Morbidity and Mortality in the United States: A Review of the Literature and Assessment of Research Needs in a Changing Climate. *Int. J. Biometeorol.* 2014;**58**:1779–1788. doi: 10.1007/s00484-013-0752-x. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
16. Hancock P.A., Vasmatzidis I. Effects of heat stress on cognitive performance: The current state of knowledge. *Int. J. Hyperth.* 2003;**19**:355–372. doi: 10.1080/0265673021000054630. [PubMed] [CrossRef] [Google Scholar]
17. Hanna E.G., Kjellstrom T., Bennett C., Dear K. Climate Change and Rising Heat: Population Health Implications for Working People in Australia. *Asia Pac. J. Public Health.* 2011;**23**:14S–26S. doi: 10.1177/1010539510391457. [PubMed] [CrossRef] [Google Scholar]
18. Heaviside C., MacIntyre H., Vardoulakis S. The Urban Heat Island: Implications for Health in a Changing Environment. *Curr. Environ. Health Rep.* 2017;**4**:296–305. doi: 10.1007/s40572-017-0150-3. [PubMed] [CrossRef] [Google Scholar]
19. IPCC . In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., et al., editors. Cambridge University Press; Cambridge, UK: New York, NY, USA: 2014. [(accessed on 10 April 2019)]. Available online: https://environmentalmigration.iom.int/climate-change-2014-impacts-adaptation-and-vulnerability-contribution-working-group-ii-fifth. [Google Scholar]
20. Kiefer M., Lincoln J., Schulte P., Jacklistch B. Climate Change and Occupational Health and Safety. NIOSH Science Blog. Centre for Disease Control and

Prevention. [(accessed on 24 October 2014)];2014 Available online: http://blogs.cdc.gov/niosh-science-blog/2014/09/22/climate-change/

21. Kjellstrom T., Briggs D., Freyberg C., Lemke B., Otto M., Hyatt O. Heat, Human Performance, and Occupational Health: A Key Issue for the Assessment of Global Climate Change Impacts. *Annu. Rev. Public Health.* 2016;**37**:97–112. doi: 10.1146/annurev-publhealth-032315-021740. [PubMed] [CrossRef] [Google Scholar]
22. Kjellstrom T., Butler A.J., Lucas R.M., Bonita R. Public health impact of global heating due to climate change: Potential effects on chronic non-communicable diseases. *Int. J. Public Health.* 2010;**55**:97–103. doi: 10.1007/s00038-009-0090-2. [PubMed] [CrossRef] [Google Scholar]
23. Kjellstrom T., Holmer I., Lemke B. Workplace heat stress, health and productivity–an increasing challenge for low and middle-income countries during climate change. *Glob. Health Action.* 2009;**2**:2047. doi: 10.3402/gha.v2i0.2047. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
24. Kjellstrom T., Kovats R.S., Lloyd S.J., Holt T., Tol R.S. The direct impact of climate change on regional labour productivity. *Arch. Environ. Occup. Health.* 2009;**64**:217–227. doi: 10.1080/19338240903352776. [PubMed] [CrossRef] [Google Scholar]
25. Kjellstrom T., Lemke B., Otto M. Climate conditions, workplace heat and occupational health in South-East Asia in the context of climate change. *WHO South East Asia J. Public Health.* 2017;**6**:15. doi: 10.4103/2224-3151.213786. [PubMed] [CrossRef] [Google Scholar]
26. Kovats R.S., Hajat S. Heat Stress and Public Health: A Critical Review. *Annu. Rev. Public Health.* 2008;**29**:41–55. doi: 10.1146/annurev.publhealth.29.020907.090843. [PubMed] [CrossRef] [Google Scholar]
27. Laaidi K., Zeghnoun A., Dousset B., Bretin P., Vandentorren S., Giraudet E., Beaudeau P. The impact of heat islands on mortality in Paris during the August 2003

heat wave. *Environ. Health Perspect.* 2012;**120**:254–259. doi: 10.1289/ehp.1103532. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

28. Leal Filho W., Echevarria Icaza L., Neht A., Klavins M., Morgan A.E. Coping with the impacts of urban heat islands. A literature-based study on understanding urban heat vulnerability and the need for resilience in cities in a global climate change context. *JCP.* 2017;**171**:1140–1149. doi: 10.1016/j.jclepro.2017.10.086. [CrossRef] [Google Scholar]
29. Leal Filho W., Icaza L.E., Emanche V.O., Al-Amin A.Q. An Evidence-Based Review of Impacts, Strategies and Tools to Mitigate Urban Heat Islands. *Int. J. Environ. Res. Public Health.* 2017;**14**:1600. doi: 10.3390/ijerph14121600. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
30. Lucas R.A.I., Epstein Y., Kjellstrom T. Excessive occupational heat exposure: A significant ergonomic challenge and health risk for current and future workers. *Extreme Physiol. Med.* 2014;**3**:14. doi: 10.1186/2046-7648-3-14. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
31. Lundgren K., Kuklane K., Gao C., Holm I. Effects of Heat Stress on Working Populations when Facing Climate Change. *Ind. Health.* 2013;**51**:3–15. doi: 10.2486/indhealth.2012-0089. [PubMed] [CrossRef] [Google Scholar]
32. Mathee A., Oba J., Rose A. Climate change impacts on working people (the HOTHAPS initiative): Findings of the South African pilot study. *Glob. Health Action.* 2010;**3**:5612. doi: 10.3402/gha.v3i0.5612. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
33. Mavrogianni A., Davies M., Batty M., Belcher S., Bohnenstengel S., Carruthers D., Chalabi Z., Croxford B., Demanuele C., Evans S., et al. The comfort, energy and health implications of London's urban heat island. *Build. Serv. Eng. Res. Technol.* 2011;**32**:35–52. doi: 10.1177/0143624410394530. [CrossRef] [Google Scholar]

34. McGranahan G., Balk D., Anderson B. The rising tide: Assessing the risks of climate change and human settlements in low elevation coastal zones. *Environ. Urban.* 2007;**19**:17–37. doi: 10.1177/0956247807076960. [CrossRef] [Google Scholar]

35. Messeri A., Morabito M., Bonafede M., Bugani M., Levi M., Baldasseroni A., Binazzi A., Gozzini B., Orlandini S., Nybo L., et al. Heat Stress Perception among Native and Migrant Workers in Italian Industries—Case Studies from the Construction and Agricultural Sectors. *Int. J. Environ. Res. Public Health.* 2019;**16**:1090. doi: 10.3390/ijerph16071090. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

36. Moda H.M., Alshahrani A. Assessment of Outdoor Workers Perception Working in Extreme Hot Climate. In: Leal Filho W., Manolas E., Azul A., Azeiteiro U., McGhie H., editors. *Handbook of Climate Change Communication: Vol. 3. Climate Change Management.* Springer; Cham, Switzerland: 2018. [Google Scholar]

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