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The Effects of Climate Change on Occupational Safety and Health

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Abstract

Climate change has far-reaching impacts not only on the ecosystems but on the anthrosphere. Its effects on the anthrosphere are multi-tiered from an entire nation down to individuals including the working population. It alters exposure to environmental hazards and the subsequent occupational risks. This review looks into how various aspects of climate change influence occupational safety and health, and provides recommendations for workplace adaptation. This review examines official data and peer-reviewed scholarly articles published in the past 15 to 20 years to draw the impacts and recommendations. It highlights the susceptibility of outdoor workers to heat and humidity caused by global warming and their works often require high physical demand and the wearing of personal protective clothing which exacerbate heat impacts. Excessive heat causes excessive sweating which could lead to dehydration and kidney disease. Mounting heat reduces working capacity and productivity besides increasing respiration rate hence exposure to chemicals through inhalation. Extreme weather events, particularly wildfires resulted from drought and increasing temperature present high occupational risk to firefighters and other outdoor workers in the wildfire zones, exposing them to extreme heat and numerous air pollutants. Global warming has been linked to increased lightning strikes and more severe heatwaves threatening workers. Flooding and more intense storms increase the occupational risks of those working on sea and in coastal areas. Climate change also alters the distribution and prevalence of disease vectors, creating new occupational risk. Adaptations should take into consideration climate change and workers' protection in building designs, coastline protection and adaptive response.
Keywords: Adaptation; Climate change; Extreme weather; Heat; Safety and health; Workplace

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Introduction

Climate change is a global phenomenon affecting the lives on Earth. The changing climate has not only affected human civilization, it has also influenced other life forms on earth and the natural landscapes. While climate change can be attributed to natural and anthropogenic causes, the latter has been considered the major driver owing to the human burning of fossil fuels which rapidly releases the carbon trapped in the fossil fuels formed over millions of years into the

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atmosphere [1]. The large amount of carbon channeled into the atmosphere over a relatively short timeframe has led to a surge in the atmospheric carbon dioxide level. To date, the mean monthly carbon dioxide level has soared past 410 ppm in comparison to approximately 380 ppm in 2008 [2]. Human activities have also resulted in the increase of other greenhouse gases in the atmosphere including methane and nitrous oxide, both of which are more potent than carbon dioxide in causing global warming [3].

Rising greenhouse gases results in the trapping of heat which enhances global warming. Since 2010, six warmest years had been recorded particularly between 2014 to 2016. The global average land and ocean temperature had risen by 0.85°C between 1880 and 2012, causing the gradual disappearance of glaciers in many parts of the world and the retreat of Arctic sea ice [2]. The warming climate catalyzes sea level rise, mainly by causing the expansion of seawater besides increasing the seawater volume through melting ice. Changes in radiative forcing and heat content of the Earth’s atmosphere are also translated into extreme weather events particularly heat waves, torrential rains and flooding, more intense hurricanes and storms [3]. These climatic changes have multiple implications on the ecosystems and the anthrosphere. Ocean warming aggravates coral bleaching and the spread of marine dead zones as less oxygen dissolves in warmer seawater. Excessive atmospheric carbon dioxide is removed by the sea acting as a carbon sink, causing ocean acidification which threatens the survival of calcifying organisms and disrupts the marine primary production system [4]. Land and ocean warming causes a shift in the distributions of plants and animals, thus, altering the compositions, structures and functions of ecosystems [5]. Changes in the natural ecosystems induced by climate change have far-reaching impacts on the human socio-economic system. Shifting distributions of fauna impact regional fisheries and forest resources, which in turn, affect food security and incomes [6]. The anthrosphere is also affected in multiple ways. Agricultural and livestock farming are impacted by changes in temperature and rainfall particularly and extreme weather events such as flood and heat wave cause significant damage to crops and farmed animals [7,8]. Changes in the distribution of pests ensuing climate change could disrupt agricultural activities and productivities [7]. Furthermore, rising sea level and extreme weather also bring damages to the shorelines and infrastructure. Climate change has prompted more stringent consideration of climatic factors in infrastructural development [9]. It gives rise to public health concern by altering the distribution and prevalence of disease vectors [10]. At this point, it is increasingly clearer that the impacts of climate change are multi-faceted and they permeate various components of the natural ecosystems and the anthrosphere. Even at workplaces, the effects of climate change cannot be entirely disregarded. Climate change has posed new risks to jobs which require outdoor exposure. More frequent heat waves and more intense storms may render working outdoors significantly more hazardous [11]. Climate change also modifies occupational risk levels, leading to higher risks in performing certain jobs which would otherwise have acceptable risks. Changing frequency of certain climate events potentially alters exposure frequency to hazards which complicates risk assessment [12]. Risk identification and assessment may become more complex with climate change as a contributing factor [13]. Variability and uncertainties in the manifestation and prediction of climate change add to such complexity. Recognizing the implications of climate change on occupational safety and health (OSH), this article aims to examine the implications in detail. It aims to look at how the various aspects of climate change give rise to or alter OSH risks. Moreover, it aims to provide recommendations for workplace adaptation in order that the risk levels can be acceptably reduced. While it is increasingly known that climate change could influence or complicate the management of OSH, research that draws the link between these two domains is far and few. Previous studies focus on developing and refining frameworks that permit climate change to be accounted for in OSH [12,14]. Some studies are region-specific, examining the impacts of climate change on OSH particularly in a temperate area [15]. Besides, there are studies which delve into the impacts on climate change on infrastructures such as electrical and telecommunication lines, coastal structures, as well as the land, sea and air transport systems, which stir new occupational concerns for workers working in and with these structures and systems [15]. There has been relatively higher interest in examining the heat effects on OSH due to warming climate in comparison to the impacts ensuing other manifestations of climate change [16-19]. There are few reviews that put this information together to clearly present the effects of different aspects of climate change on OSH, and to pinpoint the gaps which need to be filled in by future studies. This review fills the gap of presenting the OSH impacts of different aspects of climate change comprehensively.

Methods

This paper reviews official data and peer-reviewed scholarly articles written in English language which were retrieved from three online databases namely Scopus, Web of Science and PubMed. The keywords used in the literature search primarily comprised climate change, heat, occupational safety, workplace safety, occupational health, cold wave and rising sea level, extreme weather and vector-borne diseases. Articles published in the last 10 years were prioritized in the search though in many instances, it was necessary to extend the literature search to articles published in the past 15 to 20 years mainly because the articles published in this area are relatively less. The key research questions are 1) what are the OSH effects of the different aspects or manifestations of climate change? 2) what are the potential adaptations to the OSH impacts? The climate change effects on OSH were organized into themes such as rising temperature, extreme weather events and vector-borne diseases. The category of extreme weather events covers the various weather events induced by climate change such as flooding, hurricane, wildfires and drought, either directly or indirectly. Flooding for instance is associated with rising sea level due to global warming while wildfires are indirectly caused by lower precipitation and higher temperature worsened by human activities particularly farming and deforestation [20].

Effects of Rising Temperature on OSH

The average global land and ocean temperature has increased by 0.07ºC per decade since 1880 and the increase was even more pronounced since 1981 at 0.18ºC per decade. Year 2019 was the second warmest year in the past 140 years where the average global land and surface temperature was approximately 0.95ºC higher [2]. The highest average rise of global land and surface temperature was reported in year 2016 at approximately 0.99ºC [2]. The progressively higher temperature, albeit slight, has altered OSH risks particularly of workers working outdoors or in indoor environment without air-conditioning. Workers' exposure to heat and humidity frequently depends on the job activities and the work environment which they have little control over. Outdoor workers are particularly susceptible to exposure to heat and humidity and the risk is aggravated for work activities involving high physical demand [21]. From 2008-2014, 106 fatalities linked to outdoor heat were identified in the United States by the Occupational Safety and Health Administration [12]. Upon mapping the fatalities with projected temperature increases in different regions of the United States, Schulte et al. found more fatalities in areas foreseen to experience more days with temperatures above 32ºC [12]. Heat as a result of global warming can be aggravated by urban heat island effect which increases the OSH risks of workers working mostly outdoors in urban settings. The OSH risks could be compounded by non-occupational factors such as the conditions of living spaces or other jobs a worker takes on [22]. Excessive heat induces excessive sweating which could lead to dehydration. Wesseling et al found an association between chronic kidney disease among sugarcane harvesters in Central America and daily

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dehydration as a result of hot workplaces which caused profuse sweating [23]. The Intergovernmental Panel on Climate Change (IPCC) highlighted that climate change could result in physiological effects which lower work performance and capacity [24]. Climate change could increase external heat exposure which can lead to both physiological and psychological changes, the latter of which is linked to reduced human performance, hence reduced work capacity and increased accident risk [25,26]. With progressive warming, Dunne et al. predicted a drop in the working capacity of heat-exposed workers by 2050 [27]. They revealed that working capacity might have already reduced to 90% in the hottest months of the past years with mounting heat stress. They also projected that the working capacity would plummet below 40% in the hottest months by 2200 under the business-as-usual scenario. The worst impacts would most likely be felt in tropical and mid-latitude regions [27]. Upon studying the records of work-related emergency department between 2004 and 2010 in Ontario, Canada, Fortune et al. (2013) found increased risk of heat illness among men, less-experienced workers, workers with shorter employment tenure and manual workers [28]. Their study showed that government services, agriculture and construction sectors filed comparatively higher lost-time claims owing to heat illness. Exposure to heat has also been associated with higher risk of occupational injuries for instances, due to increased perspiration, higher risk of heat stress and even environmental factors such as fogging up of glasses [29]. Taking Australia for instance, projected increase in the frequency and intensity of extreme heat events will threaten not only outdoor workers but indoor workers not having access to adequate cooling systems [11]. In congruent with other studies, the Australian study also foresaw greater threat of heat stress and a decline in productivity in hot regions, due to disruption of the body cooling mechanism by high air humidity [11]. The effects of mounting heat may be aggravated by the need to wear personal protective clothing or equipment. Besides, the exposure to toxic chemicals in workplaces could be complicated by the changing environmental heat, thus introducing more uncertainties to the estimation of occupational health risk [22]. With higher temperature, the rate of respiration could increase and this raises one's exposure to toxicants through inhalation. In addition, greater environmental heat may increase the evaporation of volatile chemicals, thus potentially raising occupational exposure to chemicals. For example, workers at chemical storage facilities may experience higher chemical exposure as hotter environment could possibly send more chemicals including those accidentally leaked into the ground, to the air [30,31]. Simultaneously, increased perspiration and skin blood flow could enhance transcutaneous movement of toxicants [32]. Physical factors could potentially alter exposure to environmental toxicants as well. Higher temperatures tend to increase the rate of dispersion of aerosols and the density of air-borne particles, resulting in higher risk of chemical exposure. The high-risk occupations include workers of the metal-manufacturing, roofing and fire-fighting sectors [30]. Occupational heat exposure and drought resulted from climate change could jointly affect the mental health of workers by exerting psychological stress. The community stress due to prolonged heat and drought could also affect the working population. The psychological stress could be worsened by the loss of productivity linked to heat exposure and the fear of losing income [33].

Effects of Extreme Weather Events on OSH

Extreme weather events are multifaceted and include storms, hurricanes, wildfires, droughts and landslides [34]. Extreme weather events often manifest directly or indirectly due to changes in the climate. Sea level rise due to thermal expansion and melting of ice induced by global warming has resulted in coastline erosion as well as increased frequency and severity of flooding, particularly in low-lying regions. Sea level has been rising at a rate of 3.3 mm per year recently [2]. Climate change causes higher sea temperatures and water vapor content of the atmosphere which intensify

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tropical cyclones by increasing the associated rainfall and wind speed. Coupled with rising sea level, these variations result in alteration of occupational risks especially for workers working on the sea and along the coastline [3]. Fayard analyzed the 307 natural disasters that took place between 1992 and 2006, and found that wildfires contributed to 80 occupational fatalities, while hurricanes and floods led to 72 and 62 deaths [35]. Hinkel et al. underscored the significant coastal flood damages attributed to sea level rise and increased population in coastal floodplain by 2100. This also points to higher occupational risks of the coastal working population [36]. In the United States, 570 deaths and 1,746 injuries were reported in 2019 due to 67,504 weather events and the numbers included both occupational and non-occupational causes. Most of the deaths were caused by floods, heat waves and winter weather. It was found that there was a 17% increase in the number of weather events in comparison to 2015. However, the associated deaths and injuries declined by 19% and 39% respectively [37]. The rates of injury and fatality are dependent on the preparedness of the affected population and the governments in responding to the weather events and this forms a crucial aspect of adaptation to the increasing threats of weather events [38]. Better adaptation characterized by increased preparedness and responsiveness would facilitate the reduction of occupational and non-occupational risks arising from weather events. The data of the US National Weather Service show that the 10-year and 30-year average fatalities due to heat were the highest among 9 weather events studied and flood had the second highest average fatalities (see Figure 1) [39]. This highlighted that rising temperature and heat waves could pose the greatest climate change-related occupational concern followed by flood. In developing nations, threats of extreme weather events are more prominent. A study investigating weather extremes-induced post-traumatic stress disorder, injury, anxiety and depressive disorders among 70,842 individuals of developing nations found increase in the health conditions in comparison to reference data [34]. The occurrences of flood could introduce or change the distribution of disease vectors which have occupational implications to multiple sectors including natural resources management and agriculture [40]. Small-scale farmers in developing countries, for instance, are more vulnerable to the flood-borne diseases due to lower adaptability to this risk resulted probably from lower income, lower mechanization and lower access to information [22]. More intense storms present occupational risk to offshore workers who may have to commute frequently to offshore platforms [41]. Transportation to and from offshore platforms exposes them to the hazard of strong wind and waves brought by the storms.

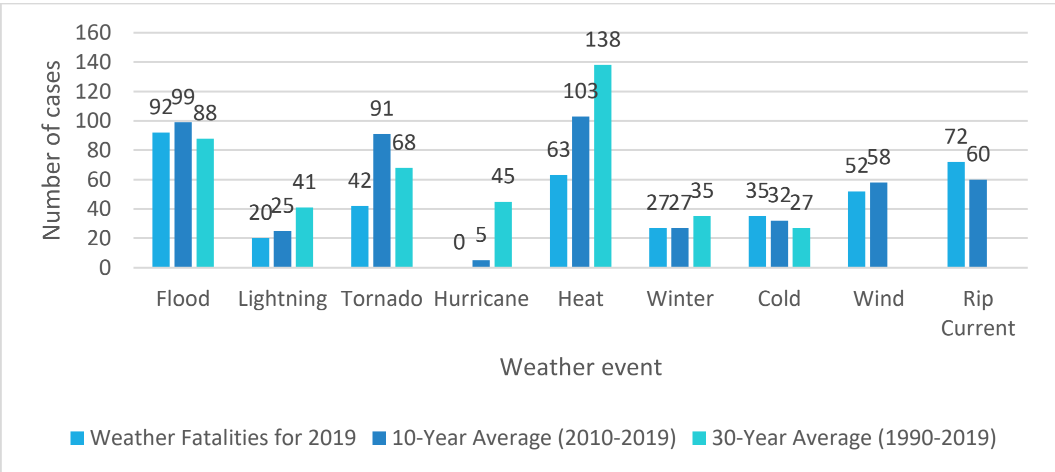

Figure 1: Weather Fatalities in the United States (adapted from US National Weather Service).

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Furthermore, heating climate and drought trigger wildfires of greater intensity and duration. This creates high occupational risk to firefighters who often need to work under harsh environment with extreme physical exertion to bring the fires under control while saving lives and properties. 19 fatalities of firefighters were reported in the battle against a wildfire in Arizona in year 2013 [42]. Three volunteer firefighters succumbed to death while fighting the unusually intense bushfires in New South Wales, Australia [43]. The high occupational risk of fighting wildfires is linked to the hot environment and the protective clothing the firefighters put on which make dissipation of heat more difficult. The risk of heat stress increases as wildfires intensify and burn longer. Wildfires also release a myriad of substances into the air such as asbestos, carcinogenic compounds and particulate matters which firefighters and other natural resources workers exposed to the wildfires could come into contact. This may give rise to additional occupational concerns [22,44]. The physical demand of outdoor work particularly putting off wildfires is likely to increase respiratory rates of firefighters, thus, causing them to breathe in more air pollutants. The exposure to air pollutants could exacerbate if the firefighters were to temporarily stay in the base camps near the wildfire sites to facilitate fire-fighting [44]. Lightning strikes of increasing frequency could pose occupational concerns. Romps et al. predicted lightning strikes to increase by 12 ± 5% for every degree Celsius increase of global average temperature which further exacerbates the risk of outdoor work [45]. In 2006-2013, 15% of lightning fatalities in the US were work-related [12]. Climate change is foreseen to cause more frequent and severe heatwaves where a rise of 3°C from the pre-industrial levels could send intense heatwave almost annually to southern Europe and every 3 to 5 years to other parts of Europe. With temperature increase assumed to stabilize at 1.5°C in 2100, it is expected that heatwave will affect more than 100 million Europeans compared to approximately 10 million currently. This could dramatically alter the occupational risks of many jobs especially the outdoor ones [46].

Vector-borne Diseases

The increase of vector-borne diseases associated with climate change has multiple occupational implications. Again, outdoor workers who have higher exposure to disease vectors such as mosquitoes, ticks and fleas are at greater risk. These workers range from those in construction, farming, natural resources management, firefighting and utility work to oil and gas fields [47]. Global warming is known to change the distribution and life cycles of vectors causing introduction of new diseases as well as introduction of vector-borne diseases into new areas [47]. For instance, the changing prevalence of malaria and Zika virus disease in Africa could expose workers in areas previously unaffected to these diseases. It has been reported that the prevalence of Lyme disease in the US has risen by more than 320% in the northeastern states of the US and outdoor workers are five times more likely to contract Lyme disease than indoor workers [48]. Besides, the increased incidences of coccidioidomycosis probably as a result of range expansion of the disease-causing fungus attributed to changing climate have affected outdoor workers [49]. Changes in vector distribution may also lead to changing pervasiveness of waterborne diarrhea which can affect workers whose jobs require contact with water [10]. Global warming has been anticipated to prolong the transmission season and the geographical distribution of arthropod vectors carrying viruses which cause encephalitis and West Nile fever, in addition to changing the range of rodents responsible for hantavirus pulmonary syndrome [50].

Occupational Adaptations

While mitigation of climate change provides the ultimate solution to the associated occupational implications, there is still a long journal towards the maturation of low-carbon practices and zero-carbon technologies. Besides, the transition to carbon neutrality is

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complicated by political and economic factors which introduce uncertainties in mitigating climate change [51]. With the impacts of climate change already manifested, it is important to adapt to the impacts while engaging in the long-term negation of the impacts. In the building sector, it is necessary to take climate change factors into the siting and design of commercial and industrial buildings to minimize the adverse effects of climate change on the safety and health of the occupants [52]. The integration of workers' protection standards in building designs particularly indoor air quality, safe access and fall protection is crucial. Rising sea level and aggravating coastline erosion will necessitate protection of the coastal areas either via engineering or ecological means [36]. Identification of the vulnerability of workers to the occupational impacts of climate change could enable preventive actions to protect workers from the impacts. For example, since outdoor workers are known to be at risk, measures such as work rotation, more breaks, provision of more shades, and emergency preparedness can be taken to reduce their risk. The design of personal protective equipment and clothing which features better heat dissipation could help reduce the adverse occupational effects of heat exposure [25]. Early warning system for identifying and predicting regional health risks would be beneficial to workers [14]. Being able to predict an outbreak for instance, would help the working population to better prepare for outbreak by altering work arrangement and work behavior while taking precautionary actions such as wearing protective clothing and undertaking vaccination. The development of adaptive response is also crucial to deal with the occupational impacts of climate change as they arise. The responses could be preventive programs, administrative procedures or development of technology [12]. Climate change factors need to be included in the health impact assessments of workers to permit a more accurate representation of the occupational risks. Due to the variable nature of climate change, uncertainties should be considered [53]. Occupational safety and public health could be co-managed since controlling vector-borne diseases for the safeguarding of public health also contributes to protection of the working population.

Conclusion

The progression of climate change implicates new and intensified occupational hazards which prompt the reconsideration of risk levels of certain occupations especially those requiring outdoor work. The variability of climate change has also added a layer of uncertainty on occupational risk assessment. While this review examines the occupational implications of various aspects of climate change, it could be limited in addressing the regional occupational impacts of climate change. The reason is that climate change varies with different geographical regions. While some areas experience higher precipitation, others may experience lower rainfall. Besides, the current research on the occupational impacts of climate change tends to focus on heat due to global warming. More studies are needed on the occupational impacts associated with other facets of climate change such as the rising sea level, melting ice, more frequent floods, more intense storms and hurricanes. Even within the domain of heat exposure, there are obvious research gaps such as the economic implications of heat on workers' productivity and the interactions of more intense heat with environmental chemicals. In terms of vector-borne diseases, more detailed studies on the tasks which increase the risk of workers' exposure to the vectors are needed.

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