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Heat Stress Impacts on Cardiac Mortality in Nepali Migrant Workers in Qatar

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Keywords
Nepali migrant workers · Heat exposure · Climate change · Cardiovascular health · Mortality · Qatar

Abstract
Background: Qatar is a major destination country for Nepali migrant workers (NMWs; main age range 25–35 years) in the construction trade. These 120,000+ NMWs are exposed to various occupational hazards, including excessive heat, and 3–4 workers die each week. Our study aimed to show whether heat exposure caused deaths. ***Methods:*** The worker population and mortality data of NMWs were retrieved from government institutions in Nepal. Heat exposure was assessed by monthly estimates of daily wet bulb globe temperature (WBGT), for in-shade conditions, from data collected at the Doha weather station from 2009 to 2017. Working in the sun during the middle of the day would add 2–3 °C to the in-shade WBGT values. Daily deaths and their causes were obtained from the records of the Foreign Employment Promotion Board (FEPB) in Nepal, 2009–2017. Interviews with returning NMWs about their working conditions and the impacts of these conditions added information. The association between the heat variable and mortality was tested with standard statistical methods. ***Results:*** The average annual death rate for NMWs in Qatar was 150 deaths/100,000. According to interviews, the majority of NMWs were found working in high WBGT (>31 °C) each working day during hot months. The major cause of these deaths was recorded as cardiovascular problems (cardiovascular disease; CVD). Unfortunately, the causes of death were poorly described, and many deaths were listed as "cardiac arrest." We included these deaths in the broader category of "cardiovascular causes." There was a strong correlation between average monthly afternoon heat levels (WBGT) and CVD mortality. It is likely that a large proportion of these CVD deaths during hot months were due to serious heat stroke. Global studies show that approximately 15% of deaths in the age group 25–35 years are due to CVD causes. However, in this NMW population, the figures were 22% during the cool season and 58% during the hot season. ***Conclusions:*** The increased CVD mortality during hot periods is most likely due to severe heat stress. As many as 200 of the 571 CVD deaths during 2009–2017 could have been prevented if effective heat protection had been implemented as a part of local occupational health and safety programs. There is an urgent need for protection against such heat effects among NMWs, and rising temperatures from ongoing climate change are further increasing the health risks. Cause of death records for workers dying in hot conditions should be more precise than "cardiac arrest."

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Introduction

Nepal is one of the countries in South Asia that sends large numbers of migrant workers to the Arab/Persian Gulf states, including Qatar. Labor migration from Nepal is approved by the Labor Act of 1985 [1], and there has been a rapid rise in the number of Nepali migrant workers (NMWs) in overseas countries beyond India [2]. Qatar is one of the top 5 destinations with the highest number of NMWs. More than half a million NMWs have migrated to Qatar for work [3]. Along with the demand for low-skilled labor, Nepalis also seek work overseas as a result of poverty, unemployment, slow economic growth, and political instability at home. The contribution of the migrant workers' remittances constitutes about 25% of Nepal's gross domestic product [3].

NMWs in some countries are vulnerable to various work environment hazards, such as extreme hot weather, poor sociocultural milieu, technology, and most significantly the "Kafala" working system that treats migrant workers as bonded laborers [4]. More than 1,300 Nepali migrants working in Qatar have died in the period 2009–2017 (1 death every second day) [5–8]. The annual mortality rate for NMWs in Qatar is 150/100,000 NMWs [8]. Occupational heat stress (exposure) and heat stroke (health effect) happens when a worker carries out uninterrupted strenuous physical activity in a hot environment [9]. ISO standards contain methods to ensure the safety and health of workers, but preventive measures are often not enforced [9].

Heat stroke and other health effects of heat exposure are noncommunicable disorders. A nationally representative cross-sectional survey determined risk factors of noncommunicable diseases (NCDs) in Nepal [10]. The most common risk factors are low fruit and vegetable consumption, alcohol consumption, smoking, low physical activity, overweight and obesity, raised blood pressure, and raised total cholesterol [10]. Heat exposure was not reported as a potential risk factor.

A study of NCDs in 31 hospitals across Nepal found that 37% of patients were admitted with NCDs, of which 38% were cardiovascular disease (CVD) [11]. Another hospital-based study showed that the relative incidence of CVD was on average 31% [12] (5–40% in different hospitals) based on data from cardiac clinics of recent years (2008–2011) throughout Nepal [13]. Another hospital-based study (all ages) showed that the main cause of death was respiratory disease with 39%, followed by infections with 21% and hepatobiliary disease with 16% [14].

CVD is an increasing problem [15] in many countries and shows a seasonal pattern, with an increase in CVD mortality during the winter months, particularly linked to cold spells affecting elderly people [16, 17]. CVD mortality in countries "close to the equator" is relatively stable through the year [17]. In countries located further away from the equator, in both the Northern and Southern hemispheres, data show that the hottest month has on average a 12–15% higher CVD mortality than the annual mean mortality [17]. There is an increase in deaths during the summer months due to heat exposure [18–21]. A study in Beijing showed that a continuation of high heat exposure persisting over several days increased the CVD mortality in all age groups [19], with a particularly high increase among people working in outdoor environments. Five consecutive days with a peak temperature over 32 °C resulted in a 20% excess of such deaths; for 11 consecutive days, that figure increased beyond 150% [19]. Climate change is likely to aggravate the existing situation, with increasing cardiovascular mortality and morbidity among the exposed vulnerable populations or significant disruption of work activities when it gets too hot to carry out normal work [22, 23]. In addition, diurnal temperature range may be an important meteorological indicator associated with global climate change that can be linked with mortality and morbidity [24]. The risk for heat illness and acute workplace injury due to exertion was higher with increasing ambient wet bulb globe temperature (WBGT) [25]. Our particular interest is whether occupational heat exposure causes cardiovascular mortality among NMWs.

Materials and Methods

Mortality data and other information on the NMW deaths in Qatar were gathered from the Nepalese government agencies related to foreign migrant workers, including the Department of Foreign Employment (DoFE), Foreign Employment Promotion Board (FEPB), the Ministry of Labor and Employment (MoLE), and from academic works (journal articles, thesis), websites, and media information [26, 27]. These sources provided information to describe the trend of NMWs in Qatar and their death rate and reported causes of death.

The database of the FEPB uses 7 groups for the classification of the deceased NMWs, namely (a) cardiac arrest, (b) heart attack, (c) suicide, (d) road traffic accident, (e) workplace accident, (f) murder, and (g) natural cause/unidentified causes. For this study, data for cardiac arrest and heart attack have been combined into 1 group as "cardiovascular deaths." Future records on mortality among NMWs should ideally consider the links of deaths with environmental conditions, such as heat.

Daily climate data for Qatar airport (1983–2017) were downloaded from the Climate Data and Heat Exposure Software and Database: Hothaps-Soft [28] (see website www.ClimateCHIP.org). The data in Hothaps-Soft for individual weather stations originate from the US NOAA GSOD database, but the user-friendly software/database (Hothaps-Soft in ClimateCHIP.org) makes various analyses and presentations much easier. Monthly Qatar grid cell climate data originating from the Climate Research Unit, University of East Anglia, were also used for longer-term heat trend analysis. The monthly averages of specific variables, gathered from both Hothaps-Soft (weather station data) and www.ClimateCHIP.org (grid cell data), were very much in agreement.

The daily minimum (min), maximum (max), and mean temperatures, as well as daily dew point estimates, were available for more than 3 decades, and their trends were analyzed. The widely used occupational heat stress index, WBGT [23], conceptually integrates temperature, humidity, wind speed, and heat radiation to assess the degree of heat stress [28–31]. The NMWs are primarily construction workers, so their daily tasks may involve work in the sun, while many activities are carried out in shaded areas or under roofs. Assuming that there is no heat radiation from the sun and that the air movement over the exposed skin is 1 m/s (similar speed as moving arms and legs in typical work situations), we can calculate WBGT (in-shade) with the method by Kjellstrom et al. [29] (see also website www.ClimateCHIP.org). Heat radiation from the sun is primarily an issue during the middle hours of a day when the heat from the sun adds approximately 2–3 °C to the in-shade WBGT [32].

Basic statistical methods were used to assess the relationship between monthly and seasonal (3-monthly) WBGT levels and the NMW mortality rates for different causes of death, i.e., Pearson correlation, linear regression, and Student's *t* test.

Results

Climate Conditions in Nepal and Qatar

The geographical features and climatic conditions of Nepal are quite different from those in Qatar. Nepal is 147,000 km^2 in area and is a predominantly mountainous country with 3 broad ecological regions: the Plain (Tarai) region approximately 100 m above sea level (masl), similar to the sub-tropical climate of the neighboring Ganges river plain in India; the Hill region (Pahad) with altitudes between 1,000 and 2,000 masl and a temperate climate; and the Mountain region (Himal) with altitudes of inhabited areas from 3,000 to 6,000 masl and a more arctic climate. The highest population density is in Tarai and Pahad, and most NMWs are likely to come from these regions. Summer temperatures can go up above 30 °C, while winter temperatures are much colder going down below 10 °C on cool days. Annual precipitation is approximately 1,000 mm in Tarai, mainly occurring during the mid-year monsoon. Kathmandu in Pahad has similar rainfall patterns, while areas closer to Himal (e.g., Pokhara) have almost 4,000 mm of annual precipitation [33].

Table 1. Qatar's share of NMWs with labor permit in GCC by year

Year[a]	Total	GCC	%	Qatar	%
2009	249,051	182,870	73.4	85,442	46.7
2010	219,965	169,510	77.1	76,175	44.9
2011	294,094	168,302	57.2	55,940	33.2
2012	354,716	240,822	67.9	102,966	42.8
2013	384,665	274,221	71.3	105,681	38.5
2014	453,543	284,392	62.7	103,486	36.4
2015	527,814	297,688	56.4	128,874	43.3
2016	512,887	292,446	57.0	124,368	42.5
2017	383,493	273,398	71.3	121,317	44.4
Total	3,380,228	2,183,649	64.6	904,249	41.4

[a] Year starts from July to June; source: DoFE, 2017 [3].

Qatar is a peninsula close to the Arab/Persian Gulf, 12,000 km^2 in area. An annual average of daily maximum temperatures above 33 °C has been measured for every year since 2000. Daily values reach 45–50 °C during the hot summer months from June through September. The climate is a desert type, very hot and dry. Unlike in Nepal, precipitation in Qatar occurs during the winter months from October to February when average temperatures remain below 20 °C. The annual average precipitation in Qatar is about 85 mm [34]. The temperatures in both Nepal and Qatar are increasing as a sign of ongoing climate change [35, 36].

Trend of NMWs in Qatar

Since the 1990s, the numbers of NMWs in the Gulf Cooperation Council (GCC) countries, such as Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates, have increased, but in recent years they stabilized just below 300,000 [3]. The NMWs in GCC represent approximately 56% of the total Nepali workers abroad. Table 1 reveals that Qatar alone accounted for approximately 40% of the NMWs in the GCC during the last decade [3]. Table 1 shows the figures we have used to calculate annual mortality rates for different causes of death.

Figure 1 shows the rising number of NMWs working in Qatar since 1994. The figures increased to over 100,000 in 2012, when Qatar won a bid in 2010 for the Soccer World Cup 2022. The number of NMWs in Qatar reached 130,000 in 2015. This type of employment provides an important source of income for their families in Nepal (Fig. 1).

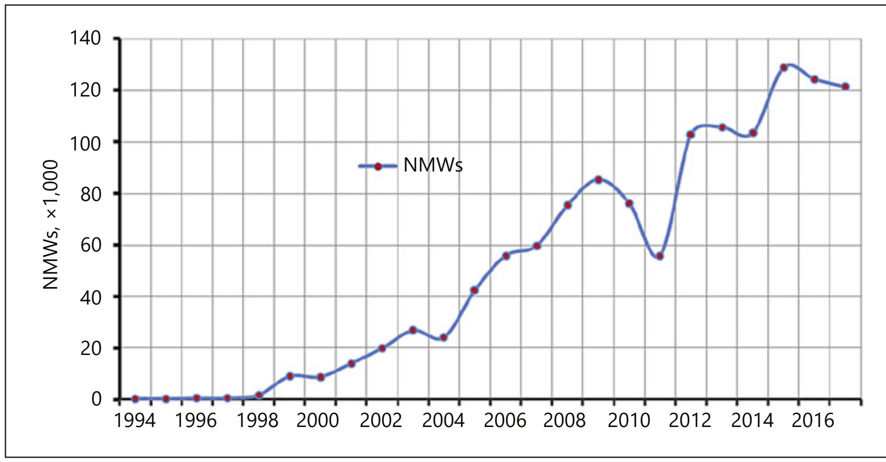

Fig. 1. Number of NMWs in Qatar by year. Source: DoFE, 2017 [3].

Table 2. Number of deaths of NMWs in Qatar according to registered cause

Year	Cardiovascular		Suicide		WPA		RTA		Murder		Natural/ other		Total
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	
2009	50	52	3	3	6	6	5	5	0	0	32	33	96
2010	60	52	10	9	13	11	7	6	18	16	8	7	116
2011	56	48	8	7	16	14	9	8	1	1	27	23	117
2012	62	44	11	8	25	18	20	14	2	1	22	15	142
2013	72	41	15	9	17	10	9	5	1	1	60	34	174
2014	73	41	13	7	19	11	18	10	1	1	52	30	176
2015	56	31	23	13	23	13	17	9		0	60	34	179
2016	65	36	18	10	34	19	24	13	0	0	41	23	182
2017	77	45	15	9	16	9	28	16	0	0	36	21	172
Total	571	42	116	9	169	12	137	10	23	2	338	25	1,354

Source: DoFE, 2017 [3]; FEPB, 2017 [8]. % is related to the annual total deaths. WPA, workplace accident; RTA, road traffic accident.

Deaths of NMWs in Qatar

Table 2 shows that cardiovascular causes are the major contributors to mortality in NMWs, accounting for 42% of the total deaths. The records in the Nepal government agencies include "cardiac arrest" as a cause of death, but this is inevitably what happens when a person dies. No autopsies or more detailed investigations were available to clarify the underlying causes and to determine whether occupational heat exposure played a role, so the actual causes of death are uncertain.

The second largest group of deaths is in the category "natural/other causes" (Table 2). It is not clear what is meant by "natural causes" of deaths of young fit men. It should also be noted that suicides occur almost as often as workplace accidents and road traffic accidents.

Figure 2 shows the monthly variation of the mortality rates per 100,000 NMWs (expressed as annual rates) due to cardiovascular causes and workplace accidents as well as the monthly average of daily WBGTmax (°C; afternoon values) plotted against the years 2009–2017. The figure shows a distinct seasonal pattern of the heat index level WBGT (°C) and mortality due to cardiac causes. The seasonal variation was tested with the Pearson correlation coefficient ($r = 0.54$ for cardiac mortality vs. WBGTmax) and was statistically significant at a 99% confidence level with $p < 0.01$. The deaths due to workplace accidents show a weaker correlation with the trend of WBGT with $r = 0.19$ (not statistically significant; $p > 0.05$).

The Pearson correlation coefficients for deaths due to road traffic accident, suicide, murder, and natural

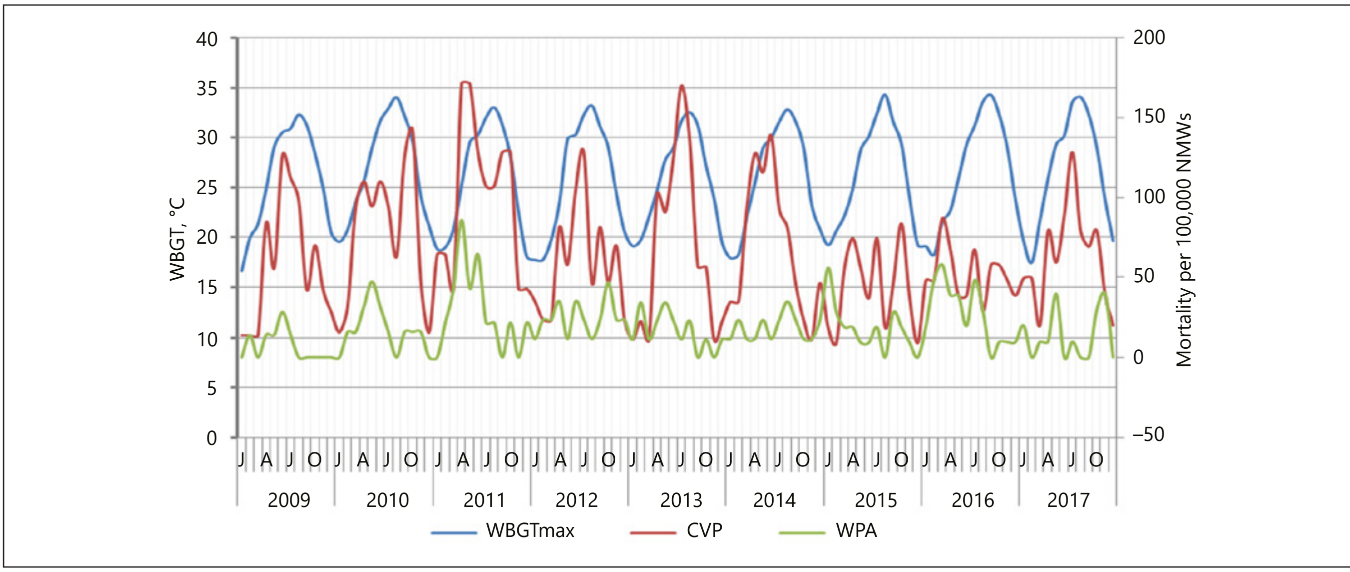

Fig. 2. WBGTmax and deaths of NMWs in Qatar (2009–2017). CVP, cardiovascular problems; WPA, workplace accident.

causes were $r = -0.063$, -0.144, -0.078, and -0.127, respectively; they were not statistically significant. However, the Pearson correlation coefficient between monthly WBGTmax (°C) and total deaths per 100,000 NMWs in Qatar was statistically significant with $r = 0.24$ and $p < 0.05$.

Figure 2 also shows that the seasonal pattern appeared to change in 2015 and 2016 with lower than expected monthly mortality rates due to cardiac causes during the hot months of the years. Apparently, the pattern returned in 2017, but the lack of a detailed individual cause of death analysis makes this uncertain.

Analysis of Qatar Temperature and Heat Stress Trends

Temperature Trends

The recent monthly means of daily maximum (Tmax) and minimum temperature (Tmin) and their longer-term decadal trends in Qatar (Table 3) show extreme heat levels in the hottest months, and the trends are strongly positive for most months. Annual averages of daily maximum and minimum temperature trends are estimated to be 0.54 °C/decade and 1.1 °C/decade with standard errors of 0.11 and 0.07 °C, respectively. The difference in the maximum and minimum trends could be due to the Urban Heat Island effect, which adds more to the nightly minimum temperatures than to the midday maximum temperatures.

These data are from Doha International Airport and are used to represent the heat situation in the populated areas of Qatar, which are close to the airport and at the same altitude. The weather station and grid cell values for Qatar are almost identical, so we assume these data indicate the heat exposure situation in shade in Qatar.

Heat Stress Index Levels (WBGT)

The calculated WBGT heat stress index levels in the hotter months (Table 4), when the air humidity is very low. These are very similar to the minimum temperatures (Table 3), while in the more humid, cooler months the WBGT levels are higher. The scale for interpretation of WBGT is different from the temperature interpretation, so a 26 °C level for WBGTmax is creating more heat stress on a person than a Tmax at the same level. It should also be remembered that the WBGT in the sun at midday is likely to be 2–3 °C higher than the full-shade values [37].

According to National Institute for Occupational Safety and Health (NIOSH; 2016), recommendations for heat protection vary according to work intensity (light, medium, heavy, and very heavy work), which in turn determine what is a safe WBGT (°C) [38]. During the hot months in Qatar, WBGTmax ranges from 29 to 34 °C (Table 4). If recommendations were followed, workers would only be able to perform light work during the hottest hours, while for heavy work, they would

Table 3. Temperatures (°C) in shade of Qatar (2015–2017) and decadal trends (1983–2017)

Month	Tmax (95% CI) 2015–2017	Trend/decade 1983–2017	Tmin (95% CI) 2015–2017	Trend/decade 1983–2017
Monthly data for four 3-month periods, starting with the hottest period				
June	42.1 (39–46)	0.49 (0.14)*	31.3 (29–35)	1.16 (0.13)*
July	42.9 (38–47)	0.46 (0.13)*	33.1 (31–35)	1.29 (0.10)*
August	42.2 (39–46)	0.46 (0.12)*	32.7 (31–34)	1.09 (0.11)*
September	39.7 (37–44)	0.52 (0.11)*	30.7 (28–33)	1.28 (0.10)*
October	36.3 (33–41)	0.46 (0.14)*	27.2 (25–30)	1.16 (0.12)*
November	30.1 (26–34)	0.07 (0.15)	22.8 (20–26)	0.97 (0.14)*
December	25.1 (22–30)	0.31 (0.26)	17.3 (14–21)	0.61 (0.20)*
January	23.6 (19–28)	0.47 (0.25)	15.4 (12–18)	1.04 (0.21)*
February	24.2 (19–30)	0.59 (0.23)*	15.8 (11–21)	0.88 (0.18)*
March	27.3 (24–31)	0.87 (0.30)*	19.6 (17–23)	1.17 (0.16)*
April	34.1 (28–40)	0.71 (0.23)*	24.0 (20–27)	1.14 (0.16)*
May	40.1 (36–44)	0.59 (0.18)*	29.5 (27–33)	1.20 (0.15)*

Tmax and Tmin indicate averages of daily maximum (and minimum) temperatures each month; confidence intervals (CI) for daily values and standard errors of trends in parentheses. * Statistically significant ($p < 0.05$) difference from zero.

Table 4. Heat index levels, WBGT (°C) in shade of Qatar (2015–2017) and decadal trends (1983–2017)

Month	WBGTmax (95% CI) 2015–2017	Trend per decade 1983–2017	Days above WBGTmax or WBGTmean					
			>26°C		>29°C		>32°C	
			max	mean	max	mean	max	mean
Six hottest months								
May	28.5 (26–31)	0.31 (0.14)*	30	10	10	0	0	0
June	29.6 (26–32)	0.17 (0.14)	30	20	20	3	0	0
July	32.4 (29–35)	0.24 (0.14)	30	29	30	20	2	0
August	34.1 (33–36)	0.62 (0.16)*	30	30	30	30	4	0
September	31.8 (30–34)	0.33 (0.16)*	30	30	30	17	1	0
October	28.7 (27–32)	0.37 (0.12)*	30	15	11	1	0	0
Average	30.9	0.34						

WBGTmax and WBGTmean indicate monthly averages of daily maximum (and mean) heat levels. The interpretation of the WBGT (° C) heat stress classification can be as follows: moderate = 28° C; * strong = 29° C+; ** very strong = 30° C+; *** extreme = 32° C+.

need to take 50–100% rest each hour as a precaution to be safe from heat stress [38]. According to interviews with returning NMWs, they were expected to work continuously even in high WBGT >30 °C. If rest periods are not allowed during such hot work, the health risk due to heat stress increases and may ultimately result in death [23].

Table 4 shows that the decadal trend of WBGT for most of the hot months is slower than for Tmax (Table 3), reflecting reduced humidity during certain months and the scale factor (Tmax = 1.3 × WBGTmax). During the 6 hotter months (Table 4), WBGTmax (afternoon heat) is higher than 26 °C every day, and in the 3 hottest months, WBGTmean (sunrise and sunset value) is also higher

Table 5. NMW mortality data by month, 2009–2017

	Cardiovascular causes		Total deaths	
	n	per 100,000 NMWs[a]	*n*	per 100,000 NMWs[a]
Hottest months				
May	57	76	123	163
June	71	94	137	182
July	81	107	130	173
August	52	69	98	130
September	51	68	88	117
October	54	72	112	149
Subtotal, mean	366	81	688	152
Cooler months				
November	29	38	102	135
December	20	27	110	146
January	24	32	106	141
February	24	32	98	130
March	37	49	113	150
April	71	94	137	182
Subtotal, mean	205	45	666	147
Total, mean	571	63	1,354	150

[a] Expressed as the equivalent annual mortality rates.

than this level every day. In the hottest 3 months, WBGTmax is above 29 °C every day.

Analysis of NMWs' Mortality from Cardiovascular Causes in Qatar

Table 5 depicts the monthly mortality data for NMWs in Qatar from 2009 to 2017 (expressed as annual mortality rates in order to make all numbers comparable). The monthly total mortality rates indicate higher levels during the beginning of the hot season (April to July) than during the rest of the year, but the difference is relatively small. The mortality rate due to cardiovascular causes in hotter months was almost double the level of the other months (Table 5). The heat starts already before May (Table 3), and the increase in the cardiovascular cause death rate in 2009–2017 began in April and reached a peak in July (Table 5).

To better visualize the effect of heat, the year is divided into four 3-month "seasons" (Table 3), and the average of daily WBGTmax (°C), as well as the total and cardiovascular mortality for each season (calculated as the equivalent annual rate per 100,000 NMWs in Qatar), is shown in Figure 3. The seasonal trends of WBGT are very regular with levels around 20 °C in the coolest season and above 30 °C in the hottest season. The total deaths and cardiovascular deaths follow similar patterns with the highest rates in the hottest season until 2014, after which the patterns change.

The average mortality rate of cardiovascular deaths for NMWs in Qatar during the years 2009–2014 was higher (73/100,000) than during the years 2015–2017 (53/100,000). A similar, but smaller, trend was found for the "total" mortality between the 2 groups of years (155 vs. 142/100,000). There is reason to believe that from 2015/2016 onwards, media attention to the workplace heat conditions played a role for the application of preventive methods, which led to the changed seasonal pattern of cardiac mortality shown in Figure 3. We have, therefore, analyzed the relationship between heat levels and cardiovascular cause mortality using the 2009–2014 dataset as the starting point.

Analysis of NMWs' Mortality due to Cardiac Causes and Heat Exposure

The relationship between monthly WBGTmax levels and mortality rates from 2009 to 2014 was plotted (Fig. 4), and the coefficient of determination (r^2) was 0.40, which implies that 40% of the variation of specific monthly data could be explained by the relationship between the heat levels and cardiovascular mortality. The linear regression function ($y = 5.5x - 71$) shown in Figure 4 with its 95% confidence interval indicates a substantial difference of cardiovascular mortality as a function of in-shade heat levels. At low heat exposure levels (WBGT = 20 °C), the average mortality rate is approximately 40/100,000 NMWs (95% CI 27–53), while at high heat levels (WBGT = 30 °C), the average mortality rate is approximately 95/100,000 NMWs (95% CI 83–107). There is substantial scatter of individual monthly data, but on average for each increase of WBGT by 1 °C, the mortality rate goes up by 5.5/100,000 NMWs (Fig. 4).

As the time trend in Figure 3 was made clearer by using 3-monthly seasonal data rather than monthly data, we also tested the correlation during the period 2009–2014 for such 3-monthly time units. The coefficient of determination (r^2) was higher at 0.50, and the linear regression function ($y = 5.7x - 71$) increased in a similar manner to the monthly data. Thus, the increase in cardiovascular cause mortality in the hotter seasons is well established.

Additional analysis was carried out concerning the relative mortality ratios as the percentage of cardiovascular causes within the total NMW mortality. Using monthly data on WBGTmax and percentage of cardiovascular cause deaths in 2009–2014, we found an r^2 at 0.59 and a linear regression function of $y = 3.4x - 44$. At a monthly

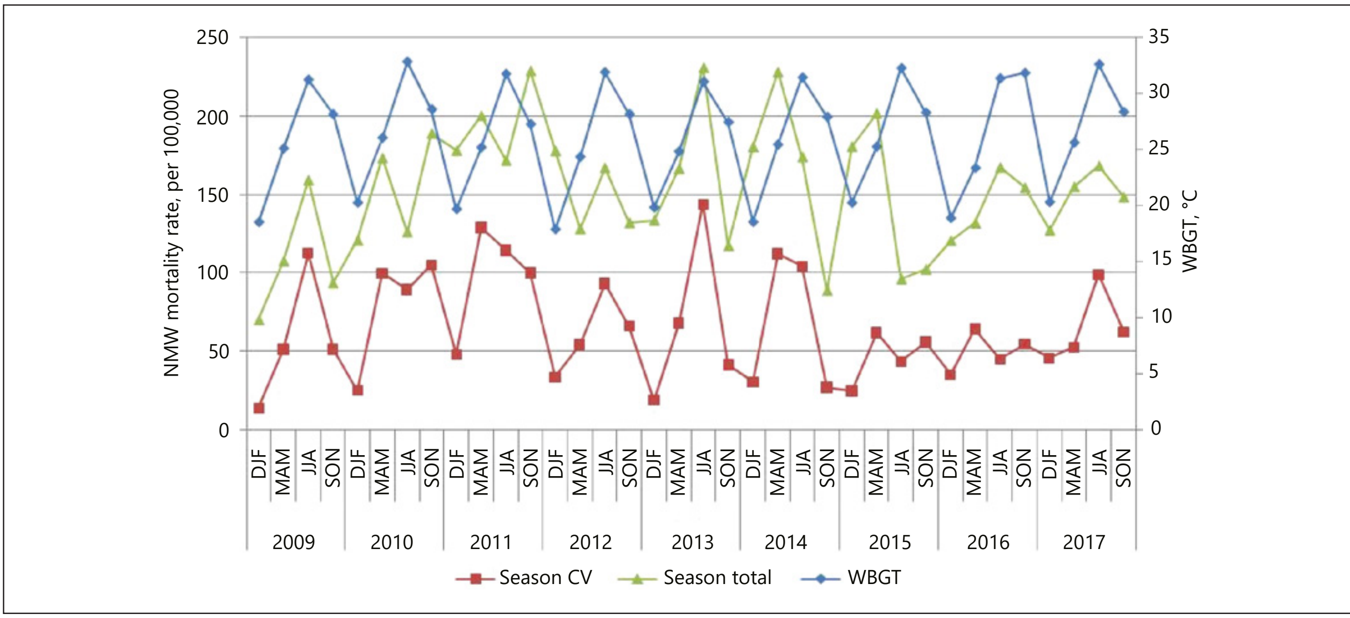

Fig. 3. 3-month seasonal trends for WBGT and NMW mortality. Daily WBGTmax values are presented in °C. Mortality rates per 100,000 NMW (annual equivalent) are indicated. Total, all deaths; CV, cardiovascular deaths; DJF, Dec., Jan., Feb.; MAM, Mar., Apr., May; JJA, Jun., Jul., Aug.; SON, Sep., Oct., Nov.

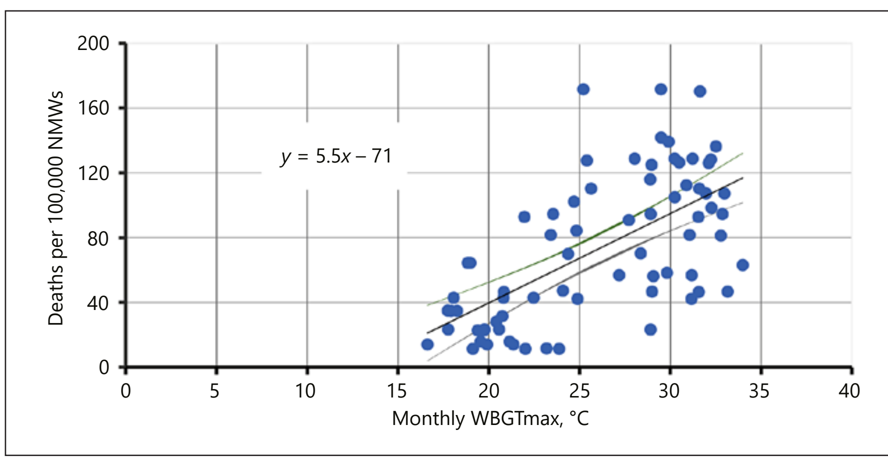

Fig. 4. Deaths due to cardiovascular causes among NMWs in Qatar, 2009–2014. Regression function: $y = 5.5x - 71$, where x is the explanatory variable (monthly WBGT °C) and y is the dependent variable (death per 100,000 NMWs).

average of daily WBGTmax of 20 °C, the rate of cardiovascular deaths was 22%, and at a WBGTmax of 30 °C, the rate of cardiovascular deaths was 58%. The increase is highly statistically significant ($p < 0.01$).

In Figure 5, we compared the recorded 3-monthly mortality rates as reported for the period 2009–2017 (CV:09–17) and the estimated 3-monthly rates based on the linear regression formula above for WBGTmax versus cardiovascular mortality (CV-est). The changed pattern in 2015–2016 is clear, and a key question is whether the change represents the impact of preventive actions.

Discussion

The above findings indicate that cardiovascular causes of death are a problem for the NMWs in Qatar, peaking during the hot summer months. People working continuously in an extremely hot environment are vulnerable to fatal heat strokes [22, 23]. According to information acquired from discussions with returned NMWs from Qatar, most of them had worked more than 12 h per day in heat levels of WBGT of 26–31 °C without appropriate breaks [3]. This heat exposure is likely to be a serious

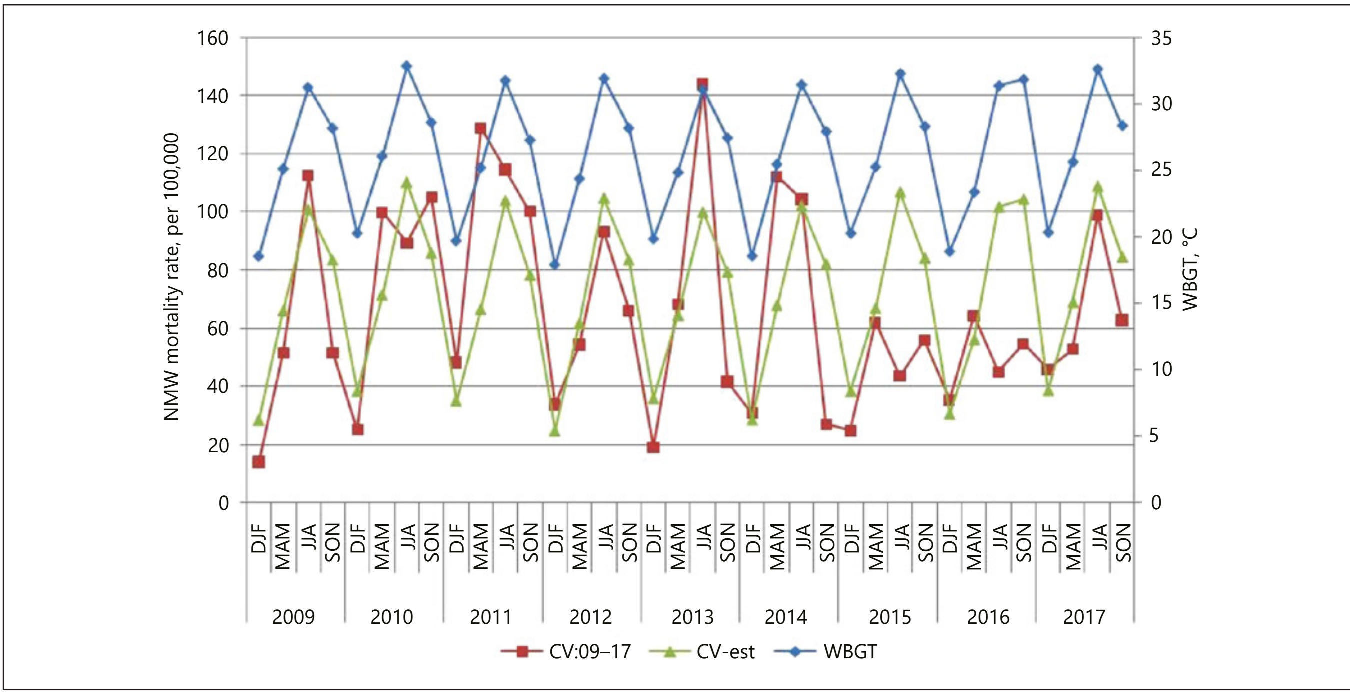

Fig. 5. 3-month seasonal trends for WBGT and NMW cardiovascular mortality, actual (CV:09–17) and estimated (CV-est) from the regression function in Figure 4. Daily WBGTmax values are presented in °C. Mortality rates per 100,000 NMW (annual equivalent) are indicated. CV, cardiovascular mortality; DJF, Dec., Jan., Feb.; MAM, Mar., Apr., May; JJA, Jun., Jul., Aug.; SON, Sep., Oct., Nov.

health risk according to the recommended occupational health standards [22, 31, 38–41].

The ages of the NMWs in Qatar ranged from 18 to 45 years, with about three-quarters of them aged 25–35 years. The age of the deceased persons was not recorded in the Nepalese government dataset but was obtained from their passport information. The majority of the deaths were in the age group 25–35 years. On average, the annual total death rate from 2009 to 2017 was 150/100,000 for the NMWs in Qatar (1,354/904,249; Tables 1, 2). At a national level, in Nepal in 2011 the estimated total mortality rate was 240/100,000 for men aged 25–35 years [42]. The difference could be due to the inadequacy of the workers' death records and could also indicate the "healthy worker effect" proposed by McMichael [43] in 1976. The NMWs are a selected group with healthy and strong bodies, and they would not be expected to die while working in Qatar. While some accidental injuries and a few cases of disease would be expected, a high proportion of cardiovascular deaths would be surprising in such a healthy group of people.

Cardiovascular causes of death in the whole group amounted to 42% of all deaths, and this relative mortality rate was 22 and 58% at a monthly WBGTmax of 20 and 30 °C, respectively. Detailed age- and cause-specific mortality rates for Nepal are not available, but comparing them with the Global Burden of Disease estimates of CVD rates at different ages [44], we find that in the age group 25–35 years the relative mortality rate for CVD is approximately 15%. The NMW finding at a low WBGTmax in winter is close to this, while the summer mortality rate due to cardiovascular causes is several times higher. Another issue to consider is the winter/summer variation of CVD deaths in general and their relation to heat exposures [20]. On average, the summer mortality in hot parts of the world is approximately 10–20% higher than the annual average. Our seasonal ratio is much higher, which indicates the particular vulnerability of people doing intensive physical work.

While the causes of death were rather vague and inadequate in many cases, e.g., "cardiac arrest," we considered that the most likely underlying cause was heat stroke. Cardiac arrest is not a diagnosis usually used in clinical trial adjudications. The term "sudden cardiac death" (SCD) is more appropriately used when a person is collapsing, i.e., acutely losing consciousness and/or dying without any previous symptoms that could point to an organ-specific diagnosis. In this sense, SCD comprises a wide spectrum of pathologies, e.g., fatal arrhythmia, fatal acute myocardial infarction, fatal stroke, fatal ruptured abdominal aortic aneurysm, acute fatal pulmonary embolism, acute heart valve rupture, etc.

Since young and healthy men very rarely have the conditions mentioned above, the assumption that their cardiac arrest is triggered by a heat stroke is adequate. We suggest that the ICD code T67 (Heat Stroke, in ICD 10) should be used for this type of cases. We found a strong correlation between monthly WBGTmax and the death rate due to cardiovascular causes (Fig. 3, 4). In the past, heat stroke mortality has primarily been analyzed as a problem for elderly people during heat waves, but there are reports on the deaths of working people during heat waves, and this is now given more attention to in occupational health assessments [32, 45, 46].

From May to October in Qatar, the average maximum temperature goes above 36 °C (Table 3), and the deaths of NMWs due to cardiovascular causes are at a higher level than during the cooler months (Table 5). Similar results were found in studies in China [19, 21]. Of particular interest was the finding that during continued periods of heat during heat waves, working people had an almost 150% increase in cardiovascular mortality [19]. Our findings are in line with this observation.

The earlier years of our study showed quite dramatic seasonal variations in the cardiovascular cause mortality. In 2015 and 2016, the pattern was different with dips in such mortality during the hottest months (Fig. 5). There was major pressure from different organizations including media [5, 27, 47–49] in 2014 on the Qatar government to undertake measures to improve occupational safety, which could explain the change in that time, but in 2017, the summer peak of cardiovascular deaths returned (Fig. 3, 5). Unless further preventive actions are taken, the high death rate is likely to continue into the future [49]. Employment opportunities for Nepalis are growing in Qatar, but the number of deaths of NMWs has not decreased. The annual number of deaths of the NMWs in Qatar accounted for 40% of the total NMW deaths in the GCC and 26% of the total NMW deaths abroad [3]. From the data presented in Figure 5, we can estimate that close to 200 NMW deaths would have been prevented if the cardiovascular mortality had stayed at approximately 50/100,000 (as in 2015–2016) during the hot summer months from 2009 to 2014.

Prevention of heat stress among these and other workers in similar conditions is very important. Employers should provide unlimited drinking water, awareness training to workers about the prevention of heat stress or minimizing its effects via acclimatization (short work exposure early in the hot season, followed by gradual increases in intensity and duration), "buddy systems" where workers do not work alone, frequent work breaks during soaring heat seasons, adjustment of tasks and procedures, etc. [23]. Comprehensive advice is available from the Heat-Shield project (see www.heat-shield.eu) [46].

An emerging issue of importance for occupational health is the effect of climate change that will bring more hot days and hotter hot days to workplaces around the world. The heat trends since 1983 show significant increases for almost every month (Tables 3, 4). Outdoor work is obviously affected, but unless work is carried out inside vehicles/equipment with air conditioning, millions of indoor workplaces are also high heat exposure areas. Many factories have large open areas without walls or air conditioning. Ongoing and future climate changes will lead to higher heat exposures for billions of people in tropical countries, most likely affecting poor people in laboring occupations, adding to the health inequities caused by other health hazards linked to climate change [50]. A key problem caused by the heat exposure is the reduction of labor productivity, recently reported as a major issue for the local construction industry [51].

Limitations of our Study

The study centered on the reported deaths and their causes as recorded in official government records; however, the process created uncertainties because of observed discrepancies in the data. For example, the FEPB maintains a database of deceased migrant workers whose kin have sought compensation but does not include data on undocumented deceased migrant workers. The classification of the causes of death is neither scientific nor clear and does not distinguish between the mode of death and cause of death. However, the deaths assigned to the "cardiac arrest" or "heart attack" categories were most likely sudden and unexpected, which fits with the likely situation for workers dying from heat stroke.

Another uncertainty was the lack of more detailed data on the type of work each worker was undertaking at the time of their death, or what preventative approaches were being implemented when they died. The data on heat levels are likely to be accurate, at least as representative data for the geographic area, but the actual heat levels at particular work sites are likely to vary. Overall, we believe that these limitations do not undermine the findings of this study.

Conclusions

During recent years, approximately 120,000 NMWs have been working in Qatar, mainly in the construction industry. Each year, more than 170 workers die, and for the period 2009–2017, the mean annual total mortality rate has been 150/100,000. Most of the workers are in the age range 25–35 years and are most likely very healthy as they were accepted for this temporary work migration. The total mortality rate is lower than the likely rate for this age group at 240/100,000, which may be a reflection of the "healthy worker effect" (a selection process) or incompleteness of data collection. In global studies, approximately 15% of deaths in this age group are due to cardiovascular causes, but in this NMW population, the death rate was in the range from 22 to 58% during periods with daily heat index (WBGT) levels reaching 20 °C (cool season) or 30 °C (hot season), respectively. The increasing cardiovascular mortality rate at higher monthly heat levels was highly statistically significant. We conclude that the increased cardiovascular mortality during hot periods most likely is due to severe heat stress among these construction workers. As many as 200 of the 571 cardiovascular deaths during 2009–2017 could have been prevented if effective heat protection measures had been implemented as a part of local occupational health and safety programs. There is an urgent need for protection for NMWs, and other groups, working in hot conditions. It is important that more precise ICD codes for cause of death are applied so that the serious effects of heat in workplaces will not be overlooked by clinicians. Based on the ongoing trends of monthly heat conditions in Qatar, we also conclude that climate change is already contributing to these occupational health risks, and it will further increase the risks in the future.

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Statement of Ethics

The yearly data (both spatial and temporal) of NMWs were obtained from the Ministry of Labor and Employment, Government of Nepal, upon submission of an official letter and proposal of the study. The ministerial consent to use its data was provided. However, as per the rules and regulation of the Ministry, the confidentiality of the names and addresses of the deceased persons was maintained while using their particular data. Similarly, a license agreement was obtained to use the Hothaps software for weather station data and analysis. The findings of the study will be officially shared with the related organizations.

Disclosure Statement

None of the authors has any disclosures in relation to the published work.

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