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ORIGINAL ARTICLE

Loss of Productivity Due to Heat Exposure among Iranian Outdoor Workers

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ABSTRACT

Direct sunlight and increased heat load influence mental and physical health of workers negatively and result in performance impairment. Activity reduction is a natural body response to increase in internal body temperature, and a compensatory mechanism to make body balanced. This study was carried out to estimate productivity loss due to heat exposure among Iranian outdoor workers. The study population was entire Iranian outdoor workers in 2014, in different job categories. Heat exposure was calculated using Wet Bulb Globe Temperature using of meteorological data from 83 synoptic stations in 30 Iran's provinces. Estimation of heat induced productivity loss was done based on graph of "work capacity". The results show that WBGT value reached its highest level during summer, especially in Bushehr (38.87 °C), Khuzestan (38.54 °C), and Sistan-and-Baluchestan (32.51 °C). While, in Chahar-Mahal-and-Bakhtiari (26.55 °C) and West-Azarbaijan (27.25°C) the least values of WBGT was observed. The highest productivity loss occurred during summer with its highest level in two provinces of Khuzestan and Bushehr (96%). In conclusion, by moving from north-west regions toward south-east regions, the level of productivity loss greatly increased. In Iran, the average of productivity loss during summer period is 60%, which is a significantly high value, in terms of climate condition and occupational distribution. Due to the important role of outdoor workers and growing trend of increase in temperature, productivity loss of this working population is undeniable. Adopting preventive strategies to increase compatibility and reduce sensitivity of exposed workers is essential.

KEYWORDS: *WBGT, Heat stress, Productivity loss, Global warming*

INTRODUCTION

Global warming results in increased heat Stress of indoor and outdoor working environments, and consequently can influence comfort and health of workers, especially outdoor workers. Apart from

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health side effects, a large body of research confirms the adverse effects of heat stress on rate of accidents, workers' behavior, and workers' performance [1-3]. Indeed, before occurrence of health related problems, at lower heat exposures, labor work capacity and productivity would be decreased [4-6].

Exposure to sunlight can decrease human performance [5] through educing physical activity. Indeed, physical activity reduction is a natural human body response to heat stress in order to diminish internal body temperature [7]. Heat, which is produced in human body while doing physical activities, increases body temperature internally and affects human health and performance negatively [4]. Decrease in human physical and mental efficiency, during heat exposure, is demonstrated in previous studies [8].

With the increase in dehydration, when total body water is reduced to less than 10%, body performance decreases dramatically [9].

In countries with low or middle income, due to some weaknesses in providing appropriate working environment, there is a higher possibility of performance reduction [5]. Estimation of heat induced productivity loss, especially for outdoor jobs (such as ranchers, foresters, workers in open pit mines, military units etc.) is very time-consuming and complicated, Therefore, productivity loss due to heat stress is usually underestimated [10].

In tropical countries with hot seasons, the increase in internal body temperature is higher than physiological coping mechanisms [11]. Moreover, by increasing Wet Bulb Globe Temperature (WBGT) from 26 °C to 30 °C, the work capacity would be rapidly reduced [11]. Up to year 2080, in the absence of any countermeasure, in most of the South-East Asian countries, Central America, and Caribbean, the productivity would be reduced by 10-27% [5]. According to ISO 7243, when the WBGT value exceeds 25°C, human work capacity begins to reduce and when it exceeds 40°C, it is very difficult to carry out any physical activities [7].

Hübler et al., carried out a survey in order to estimate health related effects of climate changes in Germany. They estimated that increase in heat induced casualties and hospitalization costs by a factor of 3 and 6, respectively. Furthermore, heat decreased the work performance between 0.1% and 0.5% of GDP [12]. For temperature higher than the comfortable level (slightly more than 20), human performance would be reduced by 3 to 50% and for temperature of 35 to 37 °C it would be risen up to 75% [12].

Literature reviews have shown the huge effects of global warming on human performance reduction and consequent productivity loss [13-14]. A large proportion of workers in Iran, including farmers, miners, fishermen, workers in agriculture section etc are exposed to direct sunlight during their working hours. According to Statistical Center of Iran, 13975691 people, out of 20844477 workers, work outdoors [15]. In addition, Iran is a vast country and the climate conditions are diverse which cause the labors to experience different ranges of heat exposure. Despite these issues, heat induced productivity loss have been given little attention in Iran.

The aim of the present study was to investigate the productivity loss due to direct sunlight exposure among Iranian outdoor workers.

MATERIALS AND METHODS

WBGT (the heat index) for outdoor environment is usually computed using natural wet-bulb (T_{nwb}) and globe temperature (T_g) according to the following equation:

(Equation 1) $$WBGT = 0.7\ T_{nwb} + 0.3\ T_g$$

Measuring WBGT by its assessing instruments in large environment is difficult and almost impossible. Thus, in the present study estimation of WBGT was done based on the data provided by different meteorological stations in the center of provinces, across Iran in 2014. However, WBGT cannot be calculated according to equation 1 due to lack of radiant temperature in meteorological data. Australian Bureau of Meteorology [5] and American college of sports medicine presented an equation for calculation of WBGT by the use of air temperature (T_a) and Relative Humidity (RH) (with the assumption of a moderately high radiation level in light wind conditions)[16]. Therefore, the provided meteorological data was converted to WBGT index using following validated equations:

(Equation 2)

$$WBGT = 0.567 \times Ta + 3.94 + 0.393 \times E$$

(*Equation 3*)

$$E = RH/100 \times 6.105 \times \exp(17.27 \times T_a/(237.7 + Ta))$$

After calculation of WBGT related to different stations, the "work capacity" graph provided by Kjellstro et al., [11] was used for estimation of heat induced productivity loss. This graph is based on NIOSH [17] and ISO [18] standards and shows the association between the individuals' work capacity and WBGT for 4 work intensities [11]. This study assumed equal rate for productivity loss and human performance reduction due to sunlight exposure. In order to estimate productivity loss in understudy provinces, outdoor working population were classified into different job groups, according to data provided by Iran Statistics Centre. Moreover, metabolism rate of these job groups were categorized (resting, low, moderate, heavy, and very heavy), using ACGIH standard. Regarding metabolism rate, contractors, gardeners, foresters, ranchers, and fisheries considered being in

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heavy category, with metabolism rate of 415 W. Other outdoor workers were estimated to have metabolism rate of more than 520 W. Thus, understudy jobs were categorized into two groups (heavy and very heavy), with 500 and 400 W work capacity losses for heavy and very heavy groups, respectively (Fig. 1.). Furthermore, productivity loss in different provinces was calculated according to the following formula:

(Equation 4) $$LP=\frac{\sum LPi \times wi}{Wt}$$

Where;

LP: average of reduction in work capacity (%)
LP_i: reduction in work capacity for each job group (heavy, very heavy) (%)
W_i: overall number of outdoor workers in each job group
W_t: overall number of outdoor workers

In the final stage, the productivity loss of each province was calculated, considering distribution of job groups and their work capacity. The results were interpolated using GIS software and Inverse Distance Weighting (IDW) method.

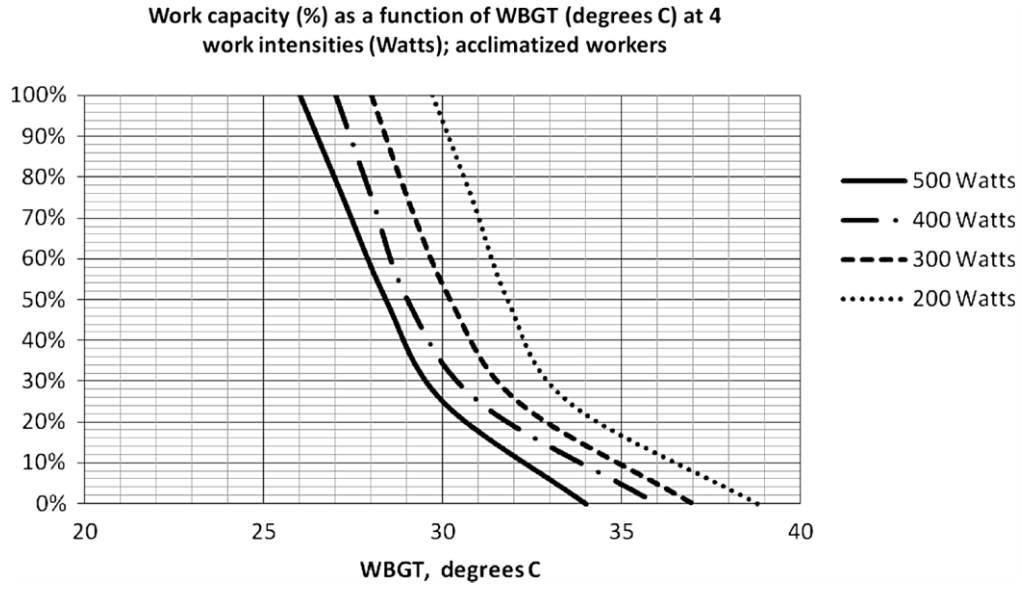

Fig.1. Association between work capacity and WBGT for work intensities

RESULT

Distribution of Iranian outdoor working population: Outdoor workers are distributed throughout Iran due to the diversity of the climate condition. As mentioned earlier, there are a total number of 13975691 outdoor workers in Iran, from which, 29.9% are engaged in agriculture. However, this estimated rate is lower than the actual number due to limitation in accessibility to some of the workers including soldiers, workers of municipal, oil, and petrochemical industries organization.

Estimation of outdoor workers exposure to heat stress: Meteorological data of 83 synoptic stations was used for calculation of WBGT during spring 2012 to 2013.

The location of weather stations, across the country, is shown in Fig.2. Overall, WBGT was higher during summer relative to other seasons, with highest values in Sistan and Baluchestan, Khuzestan, and Bushehr (34.56-45.05 °C).

In contrast, Chahar Mahal and Bakhtiari and West Azarbaijan showed the lowest WBGT values (24.37-32.53 °C) (Table 1).

Presented data in Table 1, was interpolated by GIS software and the results, separately for different seasons, are shown in Fig.3. The mean value of WBGT in autumn was shown to be in the range of 12.65-20.21 °C for majority of the provinces (green and yellow parts) and just for some parts of Sistan and Baluchestan was in the dark region (24 to 27.77 °C).

The trend of WBGT shows that, its values during all seasons, in provinces located in north part of the country were lower in comparison with those in south part (Fig.3). Overall, by moving from west-north regions to east-south regions of the country, the WBGT value increased. Thus, provinces in west-north such as West Azerbaijan have the least and the east-south provinces such Sistan and Baluchestan has the highest heat stress.

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Fig.2. Status of location of meteorological stations

Table 1. Estimated WBGT based on meteorological data across the provinces

Provinces	**WBGT**(℃)			
	Winter	Spring	Summer	Autumn
Ardabil	11.05598	23.32396	28.38080	15.54517
Bushehr	21.45208	33.80005	38.87463	26.48790
Chahar Mahal and Bakhtiari	11.19920	22.28135	26.55662	15.26421
Isfahan	14.48172	25.50904	29.04207	17.67437
Fars	16.92336	27.30027	30.37405	20.07770
Qom	14.23323	26.13519	29.47873	17.57782
Ilam	17.91204	29.27748	33.96644	22.45273
Guilan	15.69952	26.07019	32.30240	20.78451
West Azarbaijan	9.632686	21.74066	27.25156	14.52961
Qazvin	11.73327	23.60132	28.41410	15.67299
Kerman	16.70669	26.46099	28.58366	21.53953
North Khorasan	12.66828	25.85843	30.07268	16.57822
Mazandaran	16.76385	27.15132	34.56252	22.33543
South Khorasan	14.58706	25.70019	27.43033	18.07575
Khuzestan	21.91392	33.55594	38.54952	26.91350
Kohgiluyeh and Boyer Ahmad	17.23130	27.49082	32.05886	21.28332
Kordestan	8.944878	21.71566	27.02562	14.45773
Kermanshah	13.83283	25.88577	30.32280	18.63154
East Azerbaijan	11.22142	24.78496	29.88623	16.30180
Golestan	16.06504	27.87477	32.98366	19.31992
Hamadan	10.92688	22.82158	27.57338	15.46659
Lorestan	15.52119	26.84334	31.82722	19.94141
Arak	12.00576	23.34227	27.79090	16.28736
Semnan	13.46335	25.68517	29.71379	17.47140
Sistan and Baluchestan	21.85677	32.20476	32.51900	24.52638
Tehran	11.41228	23.16955	27.70755	15.39386
Yazd	16.63568	26.85108	29.18217	19.37190
Zanjan	9.710839	21.95838	27.40458	14.04588
Khorasan Razavi	13.95660	27.73606	32.36311	18.43653
Hormozgan	17.66540	27.73992	30.29454	17.59117

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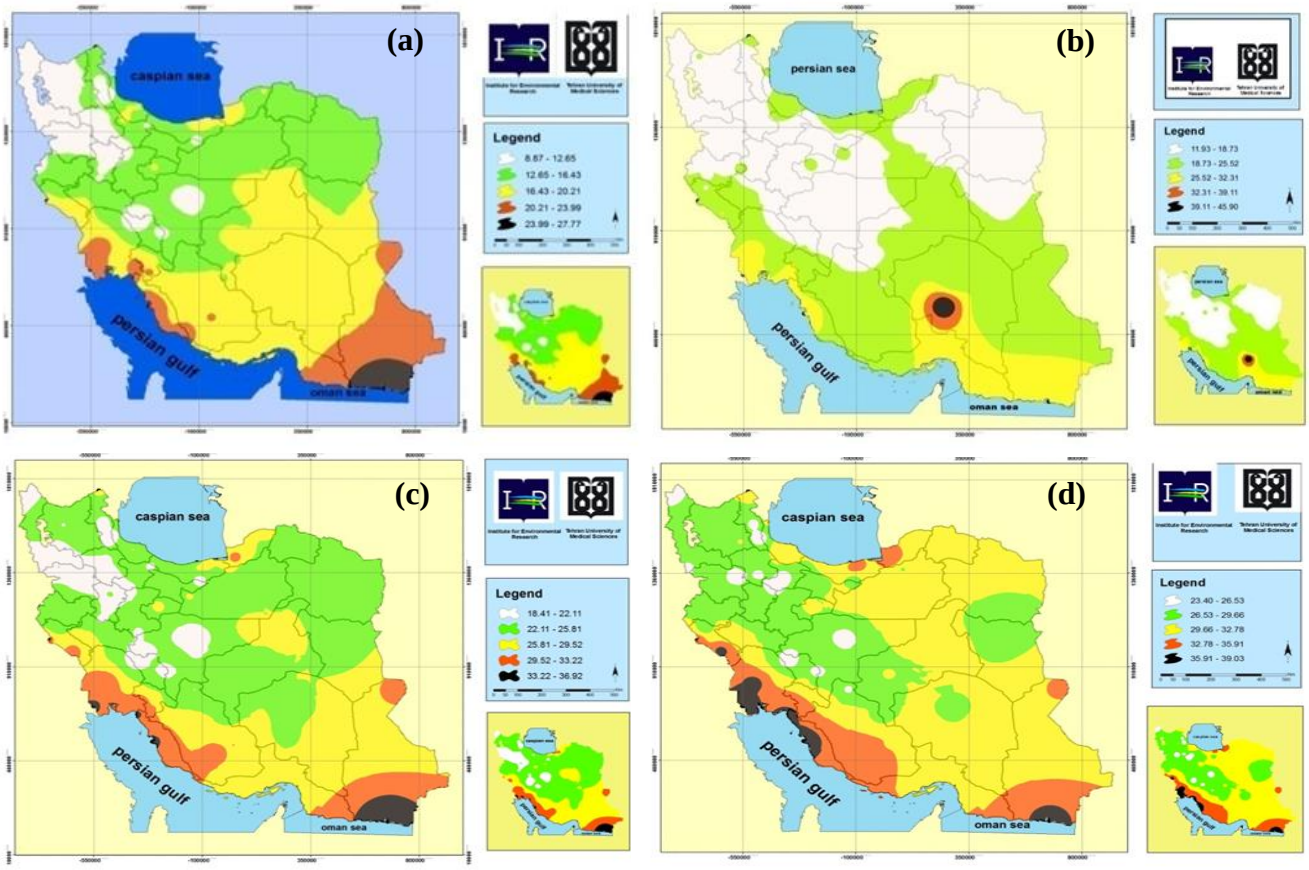

Fig.3. Heat stress status in Iran during different seasons of spring (a), summer (b), fall (c), and winter (d)

Estimation of productivity loss due to WBGT in studied provinces: Assuming that each change in labor productivity will lead to a change in work capacity, the heat induced productivity loss was calculated in this study. For this purpose, the graphs provided by Kjellstrom were used [11]. These graphs, based on ISO and NIOSH standards, show changes in individuals work capacity at different heat exposure [5]. According to the Table 2, the highest heat induced productivity loss exists during summer in above 50% of the provinces. The values of productivity loss, for outdoor workers in two provinces of Bushehr and Khuzestan were varied between 82 and 99%. In winter no productivity loss was observed in any of the provinces. Moreover, according to this graph, only two provinces of Bushehr and Khuzestan had shown productivity loss during autumn.

DISCUSSION

Productivity loss due to heat exposure among Iranian outdoor workers was investigated in the present study. Overall, exposure of outdoor workers to direct sunlight is a widespread problem in various parts of the country during summer (with maximum productivity loss of 99%, in Busherhr), which influence Gross Domestic Product (GDP). Global warming also have negative influences on productivity due to different reasons such as early fatigue, increase in treatment costs, etc. which are not investigated in the present study. This is in line with the findings by Mathee et al. on African workers. They showed that African worker, due to heat stress and its resulting effects such as sunburn, sleeplessness, irritability, and exhaustion, experienced poorer occupational output during very hot weather [19]. Construction and pottery industry workers in Thailand lost 10% to 60% of their productivity because of heat stress [20]. The findings by Kjellstrom et al. also approved the results of the present study. They reported that in countries with very hot seasons, work capacity rapidly reduces as the wet bulb globe temperature increases by 26–30 °C.

The effect of hot weather conditions on declined occupational productivity was also confirmed by Ro-Ting et al. 2009 [10].

Results of the present study confirm the direct effects of global warming on human performance and rate of productivity. Global warming reduces labor productivity in Iran by an average of 59% during summer. Moreover, heat induced productivity loss during spring is also significant (mean=16%) which impose a considerable

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economic loss. Therefore, future studies should be concentrated on proposing countermeasures in order to diminish heat exposure and its effects.

This should be noted that this is the first study in Iran and lack of access to accurate statistics pertaining to number of outdoor workers, lack of accurate data related to workers metabolism, and estimated nature of heat stress index are of the limitation of the present research.

Table 2. Estimated heat induced productivity loss across the provinces

Provinces	WBGT(℃)			
	Winter	Spring	Summer	Autumn
Ardabil	0%	0.000%	47.39%	0.00%
Bushehr	0%	93.41%	99.00%	51.0%
Chahar Mahal and Bakhtiari	0%	0.000%	6.400%	0.00%
Isfahan	0%	0.000%	57.23%	0.00%
Fars	0%	21.54%	76.24%	0.00%
Qom	0%	0.390%	62.65%	0.00%
Ilam	0%	61.95%	96.12%	0.00%
Guilan	0%	0.550%	88.42%	0.00%
West Azarbaijan	0%	0.000%	20.00%	0.00%
Qazvin	0%	0.000%	45.29%	0.00%
Kerman	0%	4.500%	45.41%	0.00%
North Khorasan	0%	0.000%	66.00%	0.00%
Mazandaran	0%	16.96%	96.38%	0.00%
South Khorasan	0%	0.000%	%13.35	0.00%
Khuzestan	0%	93.71%	96.00%	12.7%
Kohgiluyeh and Boyer Ahmad	0%	23.56%	85.89%	0.00%
Kordestan	0%	0.000%	11.10%	0.00%
Kermanshah	0%	0.000%	77.00%	0.00%
East Azerbaijan	0%	0.000%	68.80%	0.00%
Golestan	0%	28.00%	91.80%	0.00%
Hamadan	0%	0.000%	21.60%	0.00%
Lorestan	0%	12.30%	85.92%	0.00%
Arak	0%	0.000%	25.70%	0.00%
Semnan	0%	0.000%	68.60%	0.00%
Sistan and Baluchestan	0%	85.80%	88.20%	0.00%
Tehran	0%	0.000%	26.40%	0.00%
Yazd	0%	0.000%	60.00%	0.00%
Zanjan	0%	0.000%	22.70%	0.00%
Khorasan Razavi	0%	28.00%	88.80%	0.00%
Hormozgan	0%	22.80%	74.74%	0.00%
Average	0%	16.00%	59.00%	2.00%

CONCLUSION

The adverse effects of heat stress on outdoor workers' productivity have been highlighted in preceding studies. However, little has been documented related to Iranian workers. The present report has outlined the high rate of workers' productivity loss in Iran, especially during summer. Considering the vulnerability of workers to hot seasons, there is a need to implementing appropriate preventive occupational health strategies in order to reduce the adverse consequences of heat exposure in outdoor environments.

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