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Climate change and its effects on farm workers

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Abstract
Background: One of the biggest global occupational threats, especially in the outdoor workplace, is climate change and global warming, as workers are exposed to the heat stress leading to reduced performance. The aim of this study was to investigate the effect of workplace climate on labor productivity index in the agricultural sector.
Methods: In this study, data related to environmental variables of 215 synoptic meteorological stations in Khuzestan province were collected from three climatic regions (hot, mild, and cold). Using MATLAB R 2018b mathematical software based on ASHRAE/ISO7730 standard values by designing some scenarios, predicted mean vote (PMV) index, and then, labor productivity index (P) were estimated. The data were analyzed using SPSS version 25 software.
Results: The results showed that in the hot regions, there is a significant inverse relationship between P index and the main environmental variables (ta, tr, pa). In the cold regions, increasing the amount of ta and tr in light and medium workload improved the P index, but for heavy workload, it reduced productivity, and the most effective factor was increasing air vapor pressure. In the mild regions, the most effective factor in productivity was air vapor pressure. In addition, the results of Spearman's correlation coefficient showed that PMV index has a direct and significant relationship with P index.
Conclusion: Regarding the increasing trend of climate change and its effect on the desired thermal comfort and productivity, well structure and planning is needed to manage farm workers health.
Keywords: Workplace, Climate conditions, Labor, Agricultural
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Introduction

Iranian agricultural sector is divided into five main subsectors: Agriculture, animal husbandry and hunting, forestry, fishing, and agricultural services. According to the results of the census all over Iran in 2016, the share of employees in the agricultural sector in terms of urban and rural areas is 16.1% of the whole population, mostly in rural areas (1). Unfortunately, due to climate change and the increased exposure of workers to heat, occupational health risks have increased and the workers' ability and productivity have decreased (2). Especially in the manufacturing and agricultural sectors of developing countries, it has a negative impact on human resources productivity (3). In the report of the US National Aeronautics and Space Administration (NASA) entitled Climate Change and Global Warning in 2016, the first six months of this year set the record for the warmest temperature in the world (4,5). Therefore, workplace weather conditions are considered as important physical factors affecting the mental and physical performance of individuals (6,7). Farm workers are among the people who usually work between 8 to 10 hours a day, outside (8,9) and are exposed to higher levels of ambient temperature that ultimately influences their productivity as well as economic growth in a negative manner (10,11). Numerous epidemiological studies have shown that high temperatures increase mortality and health complications (12-14). On the other hand, the study of Yi et al showed that heat stress increases about 33% per 1°C increase in wet bulb globe temperature (WBGT) index (15), but unfortunately, few studies have estimated the economic costs of climate change (16). In developing countries, labor is considered as the most important factor of production, so the possible impact of climate change on this index is an important concern (17). Zander et al, estimated an 11 to 27% reduction in productivity by the end of the 21st century in warmer regions of the world (such as Asia) (18). In another study, the rate of productivity decline in various occupations of agricultural sectors in the summer due to heat was shown to be 69.3% per hour (19). In another study, it was shown that for heavy load work, productivity is reduced by 20% to 30% (20). On the other hand, raising temperatures may increase labor productivity in cold regions (21). Among climatic phenomena, extreme temperatures and heat waves have the greatest effects on individuals (22,23). Using the thermal comfort index, this study was conducted to show which climatic factors in each region affects the labor productivity and how it can be improved. This study, due to the abundance of employees in the agricultural sector, aimed to determine the effects of workplace climate on human resources productivity, in three climatic regions (cold, hot, and mild) of Iran based on the available data in 2016.

Materials and Methods

Study area

Khuzestan province is located in the southwest of Iran (31.4360° N, 49.0413° E). The region is located in a hot semi-arid climate zone and most meteorology stations have recorded a maximum air temperature of 50°C in recent summer. This region is divided into three different climatic classifications and a meteorological station was selected from each of them.

Study design

The present cross-sectional analytical study, was conducted by the initial review of the source of information and statistics of the Meteorological Organization (24); then, 215 available synoptic stations were determined based on the Morgan's table and Cochran's calculation formula. The condition for selecting these one-year synoptic meteorological stations was access to atmospheric information required to calculate the predicted mean vote (PMV) index in accordance with the latest labor productivity index reported in the agricultural sector by the National Productivity Organization (NPO) (25).

Determining the predicted mean vote index

The PMV index was used to simultaneously evaluate thermal comfort criteria such as climate variables, clothing, and type of activity (26). In this study, to calculate the PMV, index of environmental variables including air temperature (t_a) and mean radiant temperature (t_r) in °C, air vapor pressure (P_a) in mm Hg, and relative air velocity (v_a) in m/s were collected and coverage information were estimated in terms of Clo (Icl) (27,28) and activity rate (M) in w/m^2 (27,29). According to the recommendation of ASHRAE/ISO 7730 standard, spectrum -1 < PMV < 1 was used as shown in Table 1 (27,30). Also, Figure 1 shows the ASHRAE thermal sensation scale based on the PMV scale.

Table 1. PMV and P indices in the range of thermal comfort for all three types of light, medium, and heavy activities

PMV	P_l	P_m	P_h
1	104.64	105.36	115.08
0	102	102	83
-1	103.04	102.98	69.98

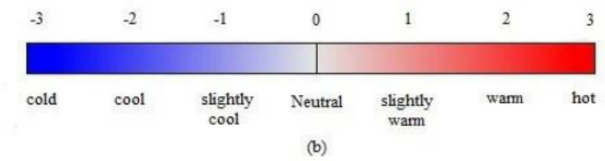

Figure 1. ASHRAE thermal sensation scale based on the PMV scale (28).

Assumptions of environmental study parameters

Kjellstrom et al estimated that the WBGT level in the outdoor environment is approximately 3°C warmer than the indoor environment (31). Therefore, in this study, the parameter of the mean annual maximum temperature in each synoptic meteorological station was used as mean radiant temperature (t_r = $t_{a\ max,}$ °C) to be closer to the more realistic value of this parameter. To provide thermal comfort, the relative humidity average of 50% and the air velocity of 0.5 m/s, which indicates its average for various outdoor works, were considered.

Assumptions of individual study parameters

In this study, the coefficient of insufficiency of workers' clothing is equal to 0.75 to investigate environmental variables affecting their productivity (31). In this research, three types of whole-body work at three levels of light, medium, and heavy workloads (125, 190, and 280 W/m^2, respectively) were used in the calculations (Figure 2).

Calculation of labor productivity index

P index was calculated using the relevant equations (32). The scenarios in all three climatic regions were explored based on the main data as input, according to Table 2, using MATLAB R 2018b software. The study procedure for each scenario of the desired climatic region is shown in Figure 2. The scenarios for calculating PMV and P indices for all three hot, cold, and mild regions are as follows:

First model: Constant air temperature and variable vapor pressure

Second model: Variable air temperature and constant vapor pressure

Third model: Variable air temperature and variable vapor pressure

Finally, for each climate region, the comparison of human productivity index in three-scenario models with human productivity index in the range of thermal comfort (P threshold) was done according to Table 3 and the effect of environmental parameters was investigated according to

Figure 3. Finally, the data were described using descriptive statistics methods including frequency, mean, and standard deviation. In the inferential statistics section, due to the non-normality of the data, to compare the average productivity of human resources in the three regions of cold, hot, and mild, Kruskal-Wallis and Dan-Bonferroni tests were applied and to examine the relationship between research variables, Spearman's correlation coefficient was used. Data were analyzed using SPSS version 25 software. Statistical significant level was considered at $P = 0.05$. The study procedure for each scenario of the desired climatic region is shown in Figure 2.

Results

Among 215 meteorological synoptic stations and according to the Köppen-Geiger classification (33), stations with an average annual temperature above 18°C were considered as hot climate regions (74 stations), from 16 to 18°C as mild regions (35 stations), and temperatures below 16°C as cold regions (106 stations) (31,34). Findings are presented in two parts: Calculation of equations of research indicators and statistical analysis. Initially, according to Table 1, the values of PMV index and labor productivity index in the range of thermal comfort for all three types of light (M < 125 W/m²), medium (125 < M < 190 W/m²), and heavy (M > 190 W/m²) activities (P_l, P_m, P_h), were calculated and became the criteria of action. Table 3 shows that in all three models of the hot regions, the human productivity index for heavy activities is more significant than the amount related to the thermal comfort range. In addition, Table 4 shows that in the cold regions, due to cold weather and air vapor pressure, especially in light and medium activities, manpower productivity has a steady trend. In addition, in these regions, in the case of medium activities, manpower productivity is maintained within the threshold of its thermal comfort, and in the case of heavy activities, increasing the air vapor pressure

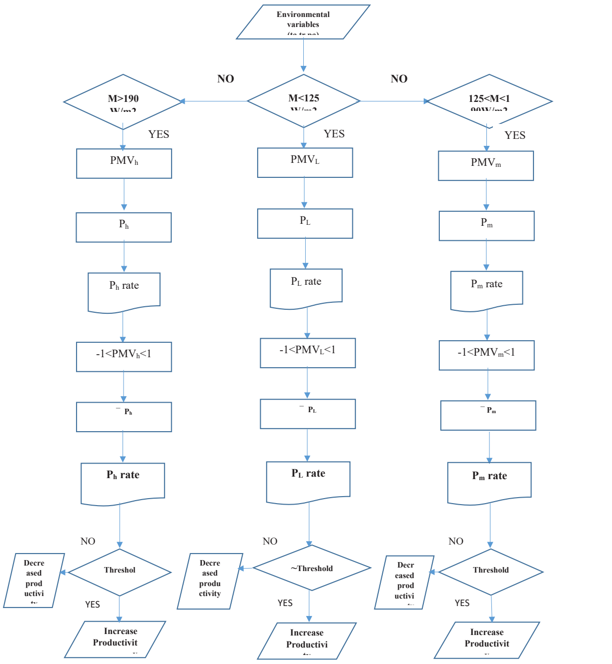

Figure 2. Procedures of the study.

reduces the human resources productivity index. Table 5 shows that in the mild regions, the productivity of manpower for light and medium activities is close to the threshold of thermal comfort, but due to the workload and heavy activities, the labor productivity index is decreased; in other words, it reduces the productivity of individuals. In mild climates, due to the stability of the trend of temperature changes, the only scenario was the first model. The diagrams in Figure 3 show and compare the results of the above-mentioned calculations.

Statistical analysis

In examining the relationship between environmental factors and P index, the average manpower productivity index in the hot regions was 131.92, in the mild regions was 112.73, and in the cold regions was 105.01, which can be interpreted in terms of thermal comfort threshold. The results of correlation calculation which are presented in Figure 4 show a strong ($R^2 = 0.98$) and significant ($P < 0.05$) relationship between t_a, t_r, and P index in the cold regions, but the relationship between p_a and P index in these regions is not strong ($R^2 = 0.18$). In the hot regions, all three main environmental variables have a strong (R^2

Table 2. Input data for calculating PMV and P indices by scenario in each climatic region

Step	IN PUT		OUT PUT
1	Main data Assumptions	t_r, t_a, p_a V_a, M, I_{clo}	PMV_l PMV_m PMV_h
2	PMV_l PMV_m PMV_h		P_l P_m P_h

Table 3. Comparison of labor productivity index in three scenario models with thermal comfort range in the hot regions

Scenario	P_l	Comfort	P_m	Comfort	P_h	Comfort
Constant air temperature, variable vapor pressure	103.04	104.64	111.02	105.36	272.59	115.08
Variable air temperature, constant vapor pressure	102	102	103.48	102	199.36	115.08
Variable air temperature, variable vapor pressure	102.27	103.04	103.29	102	177.09	115.08

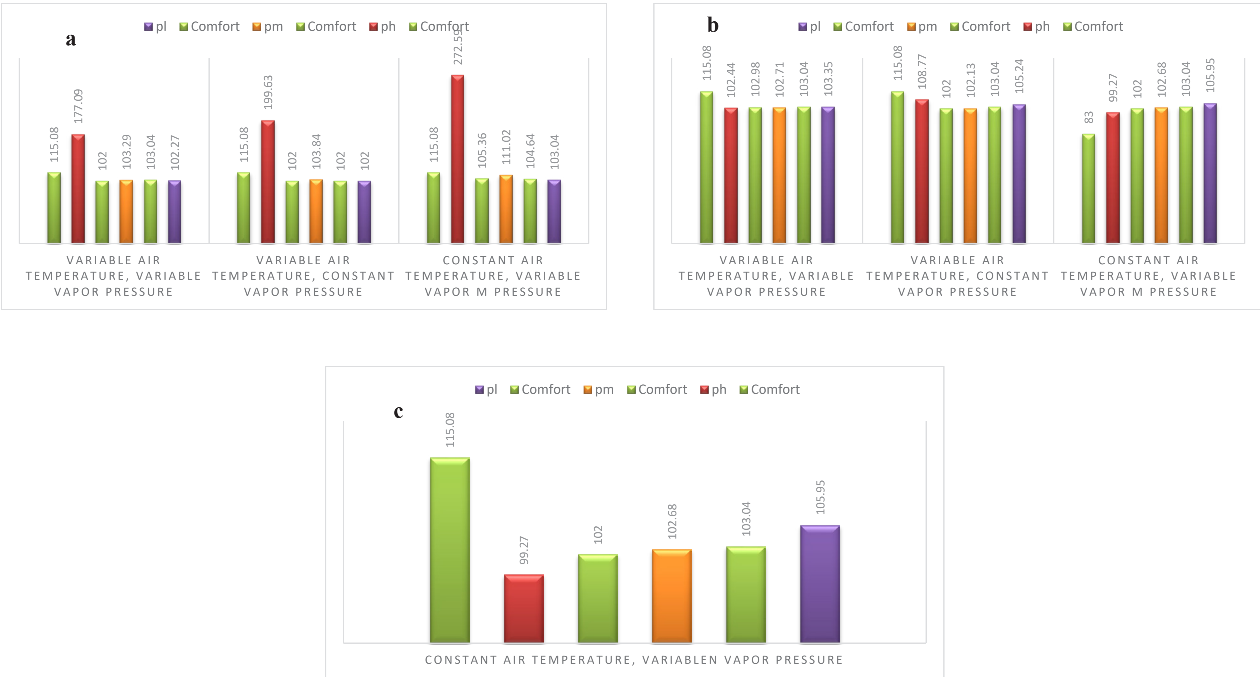

Figure 3 . Comparison of the results of climate change scenarios affecting the productivity of agricultural labor at three levels of work (light, medium, and heavy) in a) Hot climate regions, b) Cold climate regions, c) Mild climate regions with threshold of thermal comfort.

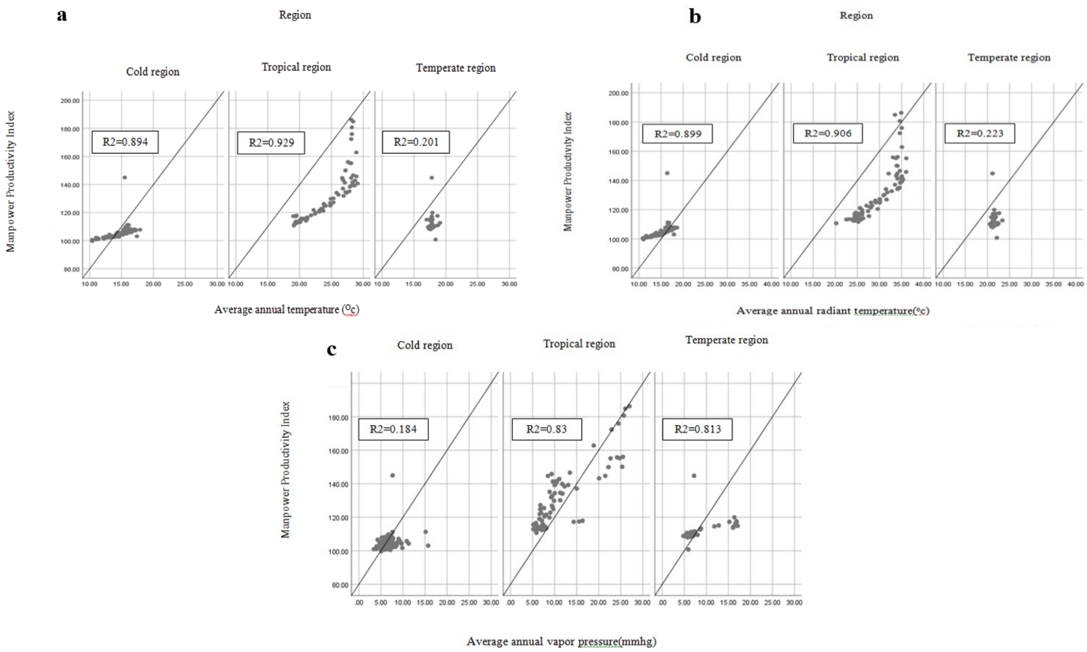

Figure 4 . The results of the correlation test of the main environmental variables with the manpower productivity index in the three climatic regions; a) The average annual temperature, b) The average radiant temperature, c) The air vapor pressure.

= 0.92) and significant correlation ($P<0.05$) with the P index. In the mild regions, only the air vapor pressure has a strong ($R^2 = 0.81$) and significant correlation ($P< 0.05$) with the P index. The results showed a strong correlation ($R^2 > 0.9$ in the cold and hot regions, $R^2 > 0.8$ in the mild regions) between the PMV index at three levels of workload (light, medium, and heavy) and manpower productivity index with a significant coefficient ($P= 0.001$). According to the comparison criterion of this study, the average total productivity obtained in the three climatic regions (116.55) with the calculated average manpower productivity in the comfort zone based on the desired values of the index (PMV) was 98.68, and also, the P index of the NPO is equal to 121, indicating that

Table 4. Comparison of labor productivity index in three scenario models with thermal comfort range in the cold regions

Scenario	P_l	Comfort	P_m	Comfort	P_h	Comfort
Constant air temperature, variable vapor pressure	105.95	103.04	102.68	102	99.27	83
Variable air temperature, constant vapor pressure	105.24	103.04	102.13	102	108.77	115.08
Variable air temperature, variable vapor pressure	103.35	103.04	102.71	102.98	102.44	115.08

Table 5. Comparison of labor productivity index in the scenario model with the range of thermal comfort in the mild regions

Scenario	P_l	Comfort	P_m	Comfort	P_h	Comfort
Constant air temperature, variable vapor pressure	103.23	103.04	101.90	102	135.60	115.08

manpower productivity in the agricultural sector is far from the desired range. Figure 5 shows that the average total manpower productivity in the three climatic regions in the agricultural sector is different from the average total manpower productivity in the desired range of thermal comfort.

Discussion

The main aim of this study was to investigate the effect of workplace climate on labor productivity index in the agricultural sector. One of the most important findings of this study is that there is a relationship between workplace climate variables, the degree of workload (metabolism), and the type of coverage of people working in different climatic regions with the level of manpower productivity because a significant population of the country's labor are active in various agricultural occupations. Comparison of the results of data analysis as occupational hazards in the outdoor workplaces and calculation of thermal comfort and manpower productivity indicators in three climatic regions of the country with the desired limits of thermal comfort (Table 2) and estimating the distance or proximity of the results with the measurement criteria in the scenarios of this study, which are shown in Figure 3, showed that the most effective factor in reducing labor productivity in cold climates for heavy jobs is the increase of air vapor pressure, which is inconsistent with the results of the study of Asadi et al, in the construction sector. This discrepancy can be due to climate change at the time of the present study compared to the time of their study (in two different decades) and their different (indoor) workplace (34). In a study by Heal and Park on thermal stress and the direct impact of climate change, it was found that increasing temperatures may increase labor productivity in cold regions (21), because the increased average annual temperature and the average radiant temperature are consistent with the increase in productivity in light and medium occupations.

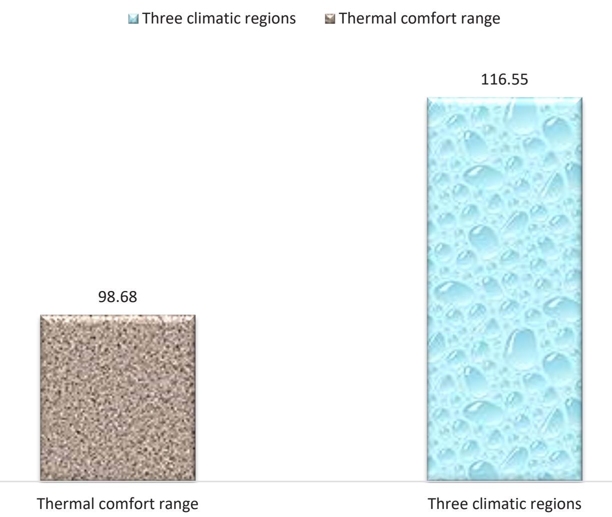

Figure 5. Comparison of the P index in three climate regions with thermal comfort range (-1 < PMV < 1) in the agricultural sector.

The results in hot reigns of this study showed that all three environmental factors (t_a, t_r, p_a) have a great impact on deviating from the desired criterion; in other words, reducing the productivity index at all three levels of workload and these results are supported by other studies (7,18). Singh et al found that at temperatures above 35°C, workers' health and productivity decreased and at 40°C in heavy workload jobs, the level of productivity reduces to one-third that may affect the agricultural economy of the area (35). The results of the studies by Kjellstrom et al, (31) and Quiller (36), using mixed linear effect models examining the impact of climate change on farmers' productivity, showed a relationship between increasing WBGT and decreasing productivity. There are significant economic effects of being exposed to excessive heat, which is consistent with the findings of the present study. Another analytical study estimated that the decline in labor productivity in the United States is due to the reduction in working time during the warmer months in terms of economic losses (37). Therefore, these studies show that reductions in human capacity for physical activity is likely to result in significant losses of work capacity due to the increase in the duration and intensity of the hot season (31,38). The findings of this study in mild regions also showed that the most effective climate factor in the workplace is the trend of changes in air vapor pressure. The other two factors of the climate of the region (R^2 = 0.8), did not show a significant effect on the labor productivity index (R^2 = 0.2), which is consistent with the results of the study of Asadi et al (34). Finally, the results showed that the PMV index has a significant relationship with the P index in all three climatic regions (P = 0.001). According to a study by Akbari et al, on 181 workers in the automotive assembly industry in two seasons of summer and winter, the relationship between heat strain and manpower productivity, was different, which can be the reason for the difference in the findings related to the use of PMV index influencing individual factors measuring the type of work of individuals (workload) in addition to environmental factors (39). Therefore, according to the findings, in heavy activities where the level of metabolism increases, and due to limitations such as different physiological readiness of workers and their adaptation to the weather conditions of the workplace, the type of clothing should be considered to improve the physical conditions in all three climatic regions. Despite other effective parameters on changes in labor productivity such as managerial factors, socio-psychological factors, cultural factors, economic factors, personality traits, and education, many reasons show that environmental conditions, including climate conditions, play a significant role in reducing or increasing the productivity of human resources (40).

Conclusion

According to the findings of the present study, PMV index has a significant relationship with P index in all three climatic regions, but the type of relationship based on the impact of environmental variables can be positive or negative. The average labor productivity index in agriculture was different from the desired amount of thermal comfort and of the NPO. As a result, due to climate change, the implementation of workplace climate control programs in the agricultural sector, which in turn will improve the performance of manpower, seems necessary to achieve economic goals.

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Ethical issues

The study was approved by the Ethics Committee of Ahvaz Jundishapur University of Medical Sciences (Ethical code: IR.AJUMS.REC.1398.719).

Competing interests

The authors declare that they have no conflict of interests.

Authors' contributions

BFD, MA, and LIG prepared data and performed model runs. BFD, MA, HR, and LIG designed the study, interpreted the results, and wrote the manuscript.

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