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Identifying factors to develop and validate a heat vulnerability tool for Pakistan – A review

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Identifying factors to develop and validate a heat vulnerability tool for Pakistan – A review

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ABSTRACT

Objective: This review will provide better insight into developing and validating a heat vulnerability assessment tool for Pakistan.
Methods: A literature search was done to identify studies onon heat vulnerability assessment published from January 2012 to January 2021 (10 years). Online databases PubMed, Google Scholar, Scopus, and Web of science were used for the literature search.
Results: Heat vulnerability can be evaluated by some specific determinants that have heat-related health events, including social, economic, environmental, housing, and geographical factors.
Conclusion: This tool will identify heat vulnerability risks and mitigate morbidity and mortality.

1. Introduction

Global warming and rapid change in climate during the past few years have been a challenge to the world, bringing several changes in the nature and atmosphere on the planet.[1] Climate change includes droughts, unusual rainfalls, the melting of glaciers, and an increase in temperature. The rise in extreme heatsignificant is one of climate change's significant outcomes.[2] The increasing heat intensity is a substantial risk to human health and life. This extreme heat is a health hazard and continues to grow as a disease burden during the past few years. A significant number of deaths have been reported in different parts of the world due to heat vulnerability.[3] Extreme heat is defined as much hotter and more humid than average. In some parts of the world, the temperature is raised to the extreme during the summers, especially.[4] Vulnerability is the state of being exposed to harm or hazard.[5]

Excessive heat harms health & well-being and can cause dehydration, acute cerebrovascular accidents, blood clots, and death. Moreover, the literature reported that heatwave caused multiple emergency hospitalizations, which turned into cardiovascular, respiratory, and renal failure.[3,6,7] According to World Health Organization (WHO 2017), during the last 15 years, the number of people exposed to heat reached 125 million globally, and around 1.7 million people died due to its intensity, of which 70000 belong to Europe.[8] A multi-country study in 400 communities from 18 countries, including countries from Asia, Europe, and North America, reported an excessive surge in deaths during the last two decades due to heat vulnerability. The reported number of deaths ranges from 30000 to 1 million, which determines that this number will keep increasing in coming years and affect every individual around the globe.[9] South Asia is the most densely populated region in the World and most prone to natural disasters. High poverty and food insecurity make South Asia vulnerable to climate change. Some parts of the region face extreme heat, and temperatures rise to 50° Celsius[10] Research reported an extreme heatwave caused 2500 deaths in India in May 2015 with a temperature rise greater than 40° Celsius. Andhra Pradesh and Telangana were the most affected regions.[11] During the same year, the number of deaths due to heat waves was 1200 in Pakistan.[12]

The vulnerable population includes old age people, children, laborers, people with chronic illness, and some low socioeconomic ethnic groups.[13] Climate change and vulnerability due to heat vary in different parts of the world. Studies suggested that each year with the change in the climate globally, heat vulnerability will continue to cause health disparities and deaths to increase up to 3 fold.[8] Heat waves burden the health sector and cause instability in the agriculture and economic sectors. It affects human health, livestock, and crops.[14] Crops do not sustain and grow properly in low or extreme temperatures. Many of the countries in Asia and Africa sustain their economy through agriculture.

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If they cannot grow crops well, the export will be low and causing economic instability.[15]

Heat waves and vulnerability have become public health problems for most countries around the globe.[8] Health system readiness and public health measures are required to tackle this issue. The occurrence of extreme heat events will continue in the future as predicted, ultimately leading to the burden of disease. Contextual preparation to tackle heat events is needed in communities. The adverse health consequences and vulnerability due to heat can be prevented by taking certain measures and developing a mechanism that can empower an early warning system.[16] By measuring heat vulnerability in resource-limited areas like Pakistan, stakeholders can target resources to zones and individuals at high risk of heat vulnerability.

Heat vulnerability can be evaluated by some specific determinants that have heat-related health events, including social, economic, environmental, housing, and geographical factors. These elements can be determined through available literature concerning field experts and related research. Different methods are applied to determine and understand heat vulnerability in the available literature, and extensive research has been conducted; therefore, it is important to review and compare this literature for developing a heat vulnerability assessment tool.

This review will provide better insight into developing and validating a heat vulnerability assessment tool. It has included 12 studies that have used different methods, variables, and analyses to construct heat vulnerability tools. Moreover, the limitations of these tools were also highlighted.

2. Methods

A literature search was done to identify studies on heat vulnerability assessment published from January 2012 to January 2021 (10 years). Online databases PubMed, Google Scholar, Scopus, and Web of science were used for the literature search. “Heat, high temperature, extreme temperature, heat waves, vulnerability, assessment, tool, index, risk, hazard, geography, geospatial, and GIS” were search terms used individually and in combination as inclusion criteria for literature to be considered for this review. Only English-language peer-reviewed articles mentioning the “development of heat vulnerability assessment tool/index” were considered.

3. Results and discussion

The characteristics of 12 studies (Fig. 1) included in this review are

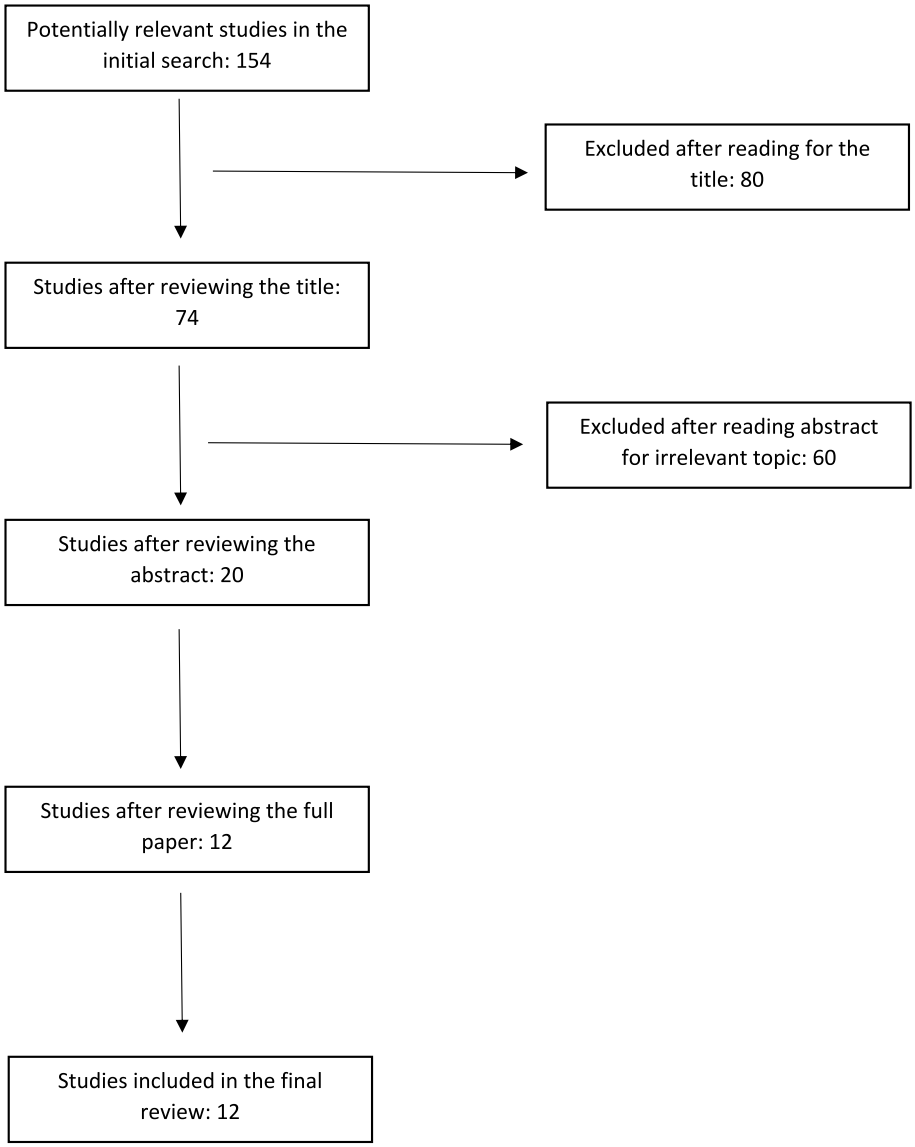

Fig. 1. Literature selection flow-diagram.

summarized in Table 1, which includes author, year of publication, study location, variables, and methods used in those studies.

3.1. Description of heat vulnerability factors

Socio-demographic, environmental, health-related variables and temperature level were the most common variables studied to determine the association with heat vulnerability in these articles for the development of the heat vulnerability assessment. These factors were broadly studied and explained in the literature, showing a significant agreement with heat vulnerability.[5,17–20] Age, poverty, language barrier, race, and social isolation were the major socio-demographic determinants examined to understand the association with heat vulnerability.[19,21,22] The correlation between an individual's health problems, including cardiovascular disorders, diabetes, asthma, obesity, and mental status with heat vulnerability, was also checked in certain studies.[23,24] Environmental-related factors such as humidity, air temperature, radiant heat, heat sources, exposure to the sun, land surface temperature, and workload duration and severity were also checked for an association with health vulnerability assessment.[22]

Other than these factors, mapping temperature level, climatic change severity, land surface temperature, housing density characteristics, housing density, and building age were looked to develop a health vulnerability assessment tool.[17,21,25]

Table 1
Summary of the studies regarding the development of heat assessment tool.

Author (year, location)	Variables	Methods
Zuhra SS et al.[17] (2019, Pakistan)	Pre-existing illness, census data, population density, housing density, normalized difference vegetation, education, nature of housing material, water availability, and minority status.	The hot spot and overlay analysis
Malik SM et al.[18] (2012, Pakistan)	Exposure to climate change, sensitivity, and coping capacity	un-weighted average
Cai Z et al.[19] (2019, China)	Rapidly developing areas, land surface temperature, building age, and housing price.	equal weight method
Johnson DP et al.[20] (2012, USA)	Age, education, race, socio-economic, pre-existing conditions, environmental	Principal component analysis
Hammer J et al.[21] (2020, Pennsylvania)	Socio-demographic, health status, and GIS data	Principal component analysis & Varimax rotation
Laranjeira K et al.[22] (2021, Germany)	Socio-demographics, heat risk perception, individual behavior, living situation, environment, heat adaption, and stress	Cross tabulation & Spearman's correlation
Nayak SG et al.[5] (2018, USA)	Census tract-level variables including environmental, sociodemographic and heat-vulnerability	Principal component analysis
Azhar G et al.[23] (2017, India)	Demographic, social, economic, health, and environmental	Principal component analysis
Zottarelli LK et al.[24] (2018, USA)	Social vulnerability, mortality, and morbidity	Negative binomial regression
Christenson M et al.[25] (2017, USA)	Population density, health factors, socioeconomic demographic, natural and built environment factors	Z-scores were calculated
Grigorescu I et al.[26] (2021, Romania)	Socio-economic and environmental vulnerability to heat-related phenomena (potential exposure, sensitivity, and adaptive capacity)	Weighted average
Samuelson H et al.[27] (2020, USA)	Housing-related: Construction type, ventilation, housing type, and building quality.	Factor analysis

3.2. Socio-economic and demographic factors

Socio-economic and demographic data have been essential indicators for heat vulnerability in different research. These indicators identify an individual's characteristics to establish the association with any health-related event. Age, race, and ethnicity are notable characteristics to understand the problem. Malik SM et al. reported that climate change daffected the population with low socio-economic status, and improving the socio-economic conditions can reduce heat vulnerability.[26] Johnson DP., et al., mentioned in their findings that socio-economic status is highly correlated with morbidity and mortality due to extreme heat. Heat vulnerability causes health hazards to the population below the poverty line.[18] Children and old people are at potential risk of heat vulnerability. The elderly's body response to heat is relatively poor than the young age group, and chronic illness is another risk factor for the elderly. Children are also susceptible to extreme heat; they also have a weaker body response to extreme heat.[27] People with low socio-economic status, poverty, and social isolation/living alone are also at a greater risk of heat vulnerability because their ability to mitigate this risk is deprived. The low socio-economic class is majorly laborers, and they work in hardships for financial sustainability. They lack social and financial support to mitigate the risk of heat vulnerability.[22] Nayak, S. G., et al., reported in his findings that unemployment, poverty, disability, language barrier and black race were at risk of vulnerability due to extreme heat, and these conditions were highly correlated with the morbidity and mortality due to heat vulnerability in findings of Zottarelli LK et al.

3.3. Pre-existing illness/health conditions

Pre-existing health issues cause more adverse health effects, combined with heat vulnerability. Azhar G et al. reported that respiratory and cardiovascular disorders were significantly associated with heat vulnerability, and hypertension is a significant risk factor for heat vulnerability.[23] However, Christenson M et al. mentioned in their findings that not only respiratory and cardiovascular disorders but individuals with diabetes, obesity, and mental status are also susceptible to heat vulnerability.[24] Literature has reported that the relative mortality risk due to heat vulnerability was 23% higher in patients with circulatory system disorder and chronic obstructive pulmonary disease (COPD) compared to the non-disease group.[28] Zuhra SS et al. also reported the same finding, pre-existing illness (diabetes) increased the susceptibility of an individual to heat vulnerability due to impaired thermoregulation.[29] It is understood from the available literature that these pre-existing health conditions cause the human body's response to slow and weak to such stresses, making them a high-risk population for heat vulnerability.

3.4. Environmental and thermal characteristics

Environmental and thermal characteristics such as the magnitude of temperature, humidity, air temperature, exposure to the sun, and land surface temperature (LST) were extensively studied in the literature available and have great agreement with heat vulnerability, especially in the urban heat-related vulnerability.[24,27] Cai, Zhi et al. used LST as an indicator and measured it on exposure, severity, and adaptability to determine heat vulnerability. The findings mentioned that the heavy industrial area has the highest temperature and is most vulnerable to high exposure, severity, and adaptability to heat waves. Moreover, rapidly developing areas and urban areas cause an increase in LST in different megacities of China.[17] Christenson M et al. mentioned in their findings that extreme temperatures and low humidity were associated with mortality. Further added, increased air surface temperature, air pollutants, and no or less vegetation have caused extreme temperature. People living in neighborhoods without greenery are at high risk of heat vulnerability.[24] Malik SM et al. reported that agro-ecological zones in

Pakistan encounter extreme temperatures, particularly during the summers, which put farmers and the labor workforce working in these agro-ecological zones at high risk of heat vulnerability.

Moreover, the coping power from the extreme heat of this workforce is low due to higher age and the unavailability of nearby health services.[26] A similar finding was reported by Laranjeira K et al., which added that the magnitude of the temperature, along with other environmental factors, increases the susceptibility and an individual's behavior and response towards it helps to cope with it. Urbanicity was a significant component of the failure of an individual's response toward heat vulnerability. The urban population faces extreme temperatures due to industrialization, polluted air, poor air quality, sedentary lifestyle, and poor water and food resources cause health hazards.[20]

3.5. Housing and building characteristics

Along with socioeconomic, demographic, environmental, and thermal characteristics, housing and building characteristics were important indicators for heat vulnerability. Indoor heat exposure is a potential cause of vulnerability for women, children, and old people. Construction type and material play an important role in indoor heat exposure. Brick walls keep indoor temperature maintained. Shade on exterior areas stops increasing indoor temperature. Ventilation and air condition availability maintain thermoregulation and reduces indoor heat. These characteristics make a housing scheme suitable for living.

Samuelson H et al. looked at the association of different housing and construction characteristics with heat vulnerability, including construction & housing type, building material quality, ventilation, and air condition status. They found that housing schemes that fail to construct houses and buildings without proper ventilation, use of quality material and effective cooling system are at high two-fold risk of vulnerability due to extreme heat.[25] Zuhra SS et al. added that the availability of green spaces in housing shames and buildings works as a thermoregulator and maintains indoor/outdoor temperatures. In urban areas, it provides great relief from extreme heat. Other than this, population and housing density contribute to heat vulnerability. The denser population and housing cause -trapping and doesn't allow wind to pass, resulting in vulnerability to heat.[29]

3.6. Development and validation of pre-existing tools/indexes

For developing a heat vulnerability assessment tool, it is essential to understand the development and validation of the pre-existing tools/indexes, methods used for analysis, and limitations of existing research. The articles added in this review specified the objectives of the construction and validation of these tools. Keeping these objectives in mind, an extensive literature search was done to determine the variables. The objectives were divided into two major categories, the first was to explore and validate the indicators for heat vulnerability,[5,18,25,29,30] and the second one was to scale up those indicators and find associations with heat vulnerability.[17,19,21–23] For validity and to understand the correlation and association, statistical tests and models were used, and many articles mentioned the use of principal component analysis (PCA).[18,21,23] Factor analysis, z-scores, and weighted & un-weighted averages were other statistical techniques used to obtain results using the heat vulnerability index. Further to the validation of the pre-existing tools most common validity and reliability measures used were content validity index (CVI) and Cronbach alpha.[5,19,20,25,30] The results of these articles are explained in detail above, and the results were significant in terms of indexing heat vulnerability.

Most of the articles informed which socioeconomic and demographic characteristics describe heat vulnerability in a better way. Other reported health effects due to the exposure and severity. At the same time, rest identified environmental, housing, and building characteristics to be important in understanding heat vulnerability. One of the articles defined the consequences of rapid urbanization causing extreme heat.

3.7. Limitations of pre-existing tools/indexes

Despite the significant results, there are certain limitations in every research. The limitations reported by these papers were grouped into four categories. The first was specific to the certain characteristics, the other was related to data, the third. The first was specific to certain characteristics, the other was related to data, the third was regarding the associations, and the final was related to validity and bias. The limitation regarding the change of some variables especially socio-economic and environmental, with the passage of time was a significant one.[17,29] Data capturing including missing baseline data and data sparsity for some indicators, was the other limitation.[5,21,22] Certain associations reported in previous literature that these tools failed to identify were a major limitation.[23,25] The information obtained regarding a study's sensitivity using survey data resulted in information bias and measurement issues.[19] One tool was validated in a moderate-temperature location, and the results may vary in high and low-temperature regions.[20]

4. Conclusion

The determinants required to construct a heat vulnerability assessment tool listed by different research papers are important, for developing a heat vulnerability assessment tool, it will be difficult to consider all of them. The development of a heat vulnerability assessment tool for Pakistan can be done using factors that are essential and required for the population of Pakistan. Considering the most suitable determinants from these categories as reported in the existing literature, i.e., geographical location, socio-economic status, exposure & severity to heat, environmental conditions, and housing factors, a heat vulnerability assessment tool should be developed and validated in different parts of Pakistan which helps in identifying heat vulnerability to risk mitigate the risk of morbidity and mortality.

Ethical approval & informed consent

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Availability of data & materials

Not Applicable.

Author's contribution

SS- Conceptualization, Methodology, Data Curation, Writing, Reviewing, and Editing.

SM- Writing, Reviewing, and Editing.

Declaration of competing interest

The author declares no competing interests.

Abbreviations

HVI	Heat Vulnerability Index
PCA	Principal Component Analysis
WHO	World Health Organization

References

1 Perkins-Kirkpatrick S, Gibson P. Changes in regional heatwave characteristics as a function of increasing global temperature. *Sci Rep*. 2017;7(1):1–12.
2 Arnell NW, Lowe JA, Challinor AJ, Osborn TJ. Global and regional impacts of climate change at different levels of global temperature increase. *Climatic Change*. 2019;155(3):377–391.
3 Bi P, Williams S, Loughnan M, et al. The effects of extreme heat on human mortality and morbidity in Australia: implications for public health. *Asia Pac J Publ Health*. 2011;23(2_suppl):27S–36S.
4 Coffel ED, Horton RM, De Sherbinin A. Temperature and humidity based projections of a rapid rise in global heat stress exposure during the 21st century. *Environ Res Lett*. 2017;13(1), 014001.
5 Nayak S, Shrestha S, Kinney P, et al. Development of a heat vulnerability index for New York State. *Publ Health*. 2018;161:127–137.
6 Fuhrmann CM, Sugg MM, Konrad CE, Waller A. Impact of extreme heat events on emergency department visits in North Carolina (2007–2011). *J Community Health*. 2016;41(1):146–156.
7 Hopp S, Dominici F, Bobb JF. Medical diagnoses of heat wave-related hospital admissions in older adults. *Prev Med*. 2018;110:81–85.
8 Campbell S, Remenyi TA, White CJ, Johnston FH. Heatwave and health impact research: a global review. *Health Place*. 2018;53:210–218.
9 Guo Y, Gasparrini A, Armstrong BG, et al. Heat wave and mortality: a multicountry, multicommunity study. *Environ Health Perspect*. 2017;125(8), 087006.
10 Bakshi B, Nawrotzki RJ, Donato JR, Lelis LS. Exploring the link between climate variability and mortality in Sub-Saharan Africa. *Int J Environ Sustain Dev*. 2019;18(2):206–237.
11 Dodla VB, Satyanarayana GC, Desamsetti S. Analysis and prediction of a catastrophic Indian coastal heat wave of 2015. *Nat Hazards*. 2017;87(1):395–414.
12 Masood I, Majid Z, Sohail S, Zia A, Raza S. The deadly heat wave of Pakistan, June 2015. *Int J Occup Environ Med*. 2015;6(4):247.
13 Gronlund CJ. Racial and socioeconomic disparities in heat-related health effects and their mechanisms: a review. *Current epidemiology reports*. 2014;1(3):165–173.
14 Ziolkowska JR. Socio-economic implications of drought in the agricultural sector and the state economy. *Economies*. 2016;4(3):19.
15 Ahmadalipour A, Moradkhani H. Escalating heat-stress mortality risk due to global warming in the Middle East and North Africa (MENA). *Environ Int*. 2018;117:215–225.
16 Kravchenko J, Abernethy AP, Fawzy M, Lyerly HK. Minimization of heatwave morbidity and mortality. *Am J Prev Med*. 2013;44(3):274–282.
17 Cai Z, Tang Y, Chen K, Han G. Assessing the heat vulnerability of different local climate zones in the old areas of a Chinese megacity. *Sustainability*. 2019;11(7):2032.
18 Johnson DP, Stanforth A, Lulla V, Luber G. Developing an applied extreme heat vulnerability index utilizing socioeconomic and environmental data. *Appl Geogr*. 2012;35(1-2):23–31.
19 Hammer J, Ruggieri DG, Thomas C, Caum J. Local extreme heat planning: an interactive tool to examine a heat vulnerability index for Philadelphia, Pennsylvania. *J Urban Health*. 2020;97:519–528.
20 Laranjeira K, Göttsche F, Birkmann J, Garschagen M. Heat vulnerability and adaptive capacities: findings of a household survey in Ludwigsburg, BW, Germany. *Climatic Change*. 2021;166(1):1–19.
21 Zottarelli LK, Sharif HO, Xu X, Sunil TS. Effects of social vulnerability and heat index on emergency medical service incidents in San Antonio, Texas, in 2018. *J Epidemiol Community Health*. 2021;75(3):271–276.
22 Grigorescu I, Mocanu I, Mitrică B, Dumitrașcu M, Dumitrică C, Dragotă C-S. Socio-economic and environmental vulnerability to heat-related phenomena in Bucharest metropolitan area. *Environ Res*. 2021;192, 110268.
23 Azhar G, Saha S, Ganguly P, Mavalankar D, Madrigano J. Heat wave vulnerability mapping for India. *Int J Environ Res Publ Health*. 2017;14(4):357.
24 Christenson M, Geiger SD, Phillips J, Anderson B, Losurdo G, Anderson HA. Heat vulnerability index mapping for Milwaukee and Wisconsin. *J Publ Health Manag Pract*. 2017;23(4):396–403.
25 Samuelson H, Baniassadi A, Lin A, González PI, Brawley T, Narula T. Housing as a critical determinant of heat vulnerability and health. *Sci Total Environ*. 2020;720, 137296.
26 Malik SM, Awan H, Khan N. Mapping vulnerability to climate change and its repercussions on human health in Pakistan. *Glob Health*. 2012;8(1):1–10.
27 Uejio CK, Wilhelmi OV, Golden JS, Mills DM, Gulino SP, Samenow JP. Intra-urban societal vulnerability to extreme heat: the role of heat exposure and the built environment, socioeconomics, and neighborhood stability. *Health Place*. 2011;17(2):498–507.
28 Sun S, Tian L, Qiu H, et al. The influence of pre-existing health conditions on short-term mortality risks of temperature: evidence from a prospective Chinese elderly cohort in Hong Kong. *Environ Res*. 2016;148:7–14.
29 Zuhra SS, Tabinda AB, Yasar A. Appraisal of the heat vulnerability index in Punjab: a case study of spatial pattern for exposure, sensitivity, and adaptive capacity in megacity Lahore, Pakistan. *Int J Biometeorol*. 2019;63(12):1669–1682.
30 Bao J, Li X, Yu C. The construction and validation of the heat vulnerability index, a review. *Int J Environ Res Publ Health*. 2015;12(7):7220–7234.