UNISDR. (2009). Terminology on Disaster Risk Reduction (No. The United Nations Office for Disaster Risk Reduction). Retrieved from: http://www.unisdr.org/we/inform/terminology

Wilby, R.L. (2012). Frameworks for delivering regular assessments of the risks and opportunities from climate change: An independent review of the first UK Climate Change Risk Assessment. The Committee on Climate Change, London.

Willows, R., Connell, R (Eds.). (2003). Climate adaptation: Risk, uncertainty and decision-making. UKCIP Technical Report.

Wolf, S. (2011). Vulnerability and risk: comparing assessment approaches. Natural Hazards, 61(3), 1099–1113. https://doi.org/10.1007/s11069-011-9968-4

ID 1602 | THE SPATIAL DISTRIBUTION OF URBAN HEAT VULNERABILITY AND COPING STRATEGIES IN BEIJING

Chen Kai[1]; Tang Yan[1]
[1]Tsinghua University
lockepark@126.com

1 INTRODUCTION

Under the influence of global climate change and local urbanization, the heat wave is thought to be more intensified and frequent. So far, the definition of heat wave has not been reached a general agreement all over the world, but severe consequences caused by heat waves on health effects have been demonstrated in many cities. With the constant process of Asia's urbanization, heat wave events will be the uppermost one of extreme weather conditions that Asian cities have to confront in the future (IPCC,2014). Thus, it is emerging objectives for urban planning that how to efficiently reduce the urban vulnerability and prevent public health from the current or potential risk of heat wave events.

Similar to other extreme weather conditions, impact areas of heat wave event are distributed unevenly. Thus, before reducing urban heat vulnerability (UHV) by means of urban planning, to identify the place and people vulnerable to heat waves is the fundamental basis for variant planning strategies. In terms of spatial pattern caused by the heat wave, the intra-urban variation of magnitude and duration during heat waves is significant. Some studies find urban heat island (UHI), a atmospheric phenomena that city area warmer than its countryside, aggravates the intensity of heat wave events within the urban area (Yang and Chen et al., 2015). In turn, higher temperature during heat wave events make UHI effect more significant. With the interaction between heat waves and UHI, urban residents have to be suffered from a higher risk of consistent heat stress. In addition to the variation of geographical range, the difference of heat-related health is another aspect need to be identified. Under the same weather condition, some people may be affected more than others. The research from public health recognizes general characteristics of people that are vulnerable to heat waves by the case study of heat-related mortality and morbidity, which includes age, economic characteristics, pre-existing health condition and thermal environment (Harlan and Brazel et al., 2006). Therefore, mapping UHV, which emphasize not only vulnerable areas, but also susceptible people, is urgently needed.

Through the lens of international experiences, UHV mapping is the key instrument to support technologically the implementation of heat waves prevention and mitigation (Wilhelmi and Purvis et al., 2004). In the cooling actions of eighteen American cities, UHV assessment is widely adopted as a necessary part (GCCA, 2014). For the Birmingham's climate change adaptation action, UHV is utilized in identifying priority areas to improve the resilient capacity (Birmingham city council, 2012). Similarly, based on the map of UHV in Australian capital cities (NCCARF, 2013), Moreland UHI effect action plan identifies five types of priority areas (Moreland city council, 2016). Thus, the first section of this article summarizes the recently progress in UHV assessment, in order to select the comprehensive framework presented for Beijing central city.

2 PROGRESS IN UHV ASSESSMENT

Although UHV assessment is considered as an emerging field in vulnerability studies, the method and index system of UHV is interacted with that of conventional vulnerability research. In view of the different perspective and discipline background, the frameworks (Figure 1)adopted in the assessment of UHV have not been reached a consensus, which are derived from two categories of definition of vulnerability in the context of climate change— biophysical vulnerability and social vulnerability (Brooks,2003). The biophysical vulnerability refers to the influence extent caused by external hazard, which is arisen from the evaluation of natural hazards and their impacts. In the conceptual framework of biophysical vulnerability, a function of hazard, exposure and sensitivity, biophysical conditions have more fundamental impacts on the final result than other indicators. Although this term is seldom used to describe vulnerability recently, similar concepts and frameworks are prevalent in the field of risk assessment. The research of ASCCUE project firstly incorporated the Crichton’s Risk Triangle into assessing the heat wave risk within UK’s urban areas (Lindley and Handley et al., 2006). However, the vulnerability of the Crichton’s Risk Triangle should be referred to as sensitivity of biophysical vulnerability, because there are similar in focusing on the demographic characteristics rather than on the adaptive capacity of people. Following this risk assessment methodology, (Tomlinson and Chapman et al., 2011) considered UHI effect as a nocturnal form of heat wave hazard and made some attempt to evaluate the risk of UHI effect. However, this assessment framework can’t present the ability of people in coping with the outcomes and effects of heat waves, which tends to make the result deviating from the original objective.

Compared with the biophysical one, the social vulnerability is described as a state that is rooted within a system before it encounters a hazard event (Allen,2003). In this case, it is thought that vulnerability is determined by the inherent characteristics, such as sensitivity, adaptive capacity of people, rather than any particular type of natural hazard. After the social vulnerability index (SoVI) was developed and presented for all American areas (Cutter and Boruff et al., 2003), this concept was gradually prevalent in different researches. Taking into account the universality of social vulnerability, some studies made some modification to improve its pertinency. (Reid and O’Neill et al., 2009) firstly applied the framework of social vulnerability to the heat waves by means of some specific heat risk factors and developed the heat vulnerability index (HVI). Although some studies followed and validated this conceptual framework, temperature data was utilized to overlay and identify the hot-spot areas, where high heat vulnerability is coincided with high temperature(Wolf and Mcgregor et al., 2013), or to improve the effectiveness of HVI model in predicting the heat-related mortality (Harlan and Declet-barreto et al., 2013; Maier and Grundstein et al., 2014). A modified HVI (extreme heat vulnerability index, EHVI) which was developed by (Johnson and Stanforth et al., 2012) added three environmental indicators related with health impacts of extreme heat and highlighted the role of exposure to heat. Because the vulnerability which are exclusive of exposure and specific hazard sometimes can’t direct proper prevention and mitigation planning, comprehensive concept of vulnerability was presented in the IPCC third assessment report, where vulnerability was defined as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes”(IPCC,2001). From the perspectives of exposure, sensitivity and adaptive capacity, (Wilhelmi and Hayden et al., 2010) developed a specific analysis flow to assess UHV, (NCCARF, 2013) attempted to incorporate the indicator of heat wave hazard into the framework.

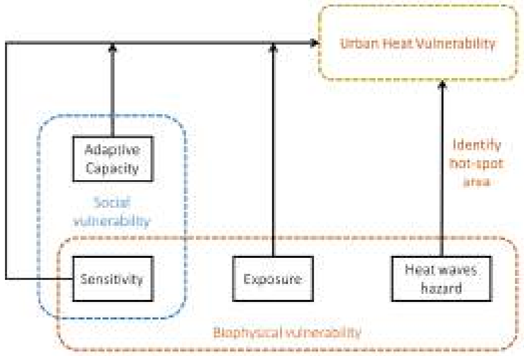


Figure 1 - Conceptual frameworks for UHV assessment.
source: authors’ elaboration

Note: The boxes with rounded corner represent the main conceptual frameworks adopted in the related literature. The boxes with black outline represent the important component derived from above conceptual frameworks.

In summary, the assessment of UHV is transformed from unilateral evaluation to comprehensive emphasis, this trend also can be discovered in the field of risk management. Based on the risk assessment framework which is composed of hazard, exposure and vulnerability, (Dong and Liu et al., 2014; Xie and Wang et al., 2015) respectively evaluated the heat wave risk at the city-scale and nation-scale of China. Due to the exposure independent of vulnerability, the contribution made by biophysical indicators is more dominant within the framework. Compared with the progress in UHV assessment abroad, it is an emerging field which has just gained widely attention in China. There are two questions need to be responded in this study: (i) Previous quantitative studies mainly focused on the city-scale in China, how to further implement the assessment methodology into the fine-scale, like sub-district ? Although the assessment at city-scale can help policy-maker directly recognize the overall degree of heat vulnerability, it can't be worked not only as a guideline for distributing the resource of disaster prevention and mitigation, but also as a communication tool for informing people of their high risk state.(ii) As the important part of climate-change risk management and adaptive planning, how to fill the gap between the result of UHV assessment and specific planning methods? If there is no efficient ways that direct the result into implementation, the UHV assessment will be invalid. Therefore, this study utilizes the central city of Beijing as a case study area and puts emphasis on following issues: (1) Setting up the assessment framework of UHV and presenting it for Beijing central city, (2) By overlaying the result of heat vulnerability and heat waves hazard, hot-spot areas will be identified as priority for mitigation strategies and adaptive design, (3) From the perspectives of disaster prevention and mitigation, three specific strategies are presented for priority areas. Thereby, as a spatial decision support tool, this study aims to help policy maker to achieve the more efficient performance of mitigation measures towards the higher vulnerable inhabitants and communities. Meanwhile, for urban inhabitants, the spatial mapping of heat vulnerability can be used for identifying their health conditions during heat waves.

3 STUDY AREA

Beijing, the capital city of China, neighbored by Hebei Province and Tianjin Municipality, is composed of 16 districts, with a total land area of 16,410 km2 and a total population of 21.5 million by the end of 2014. The study area is the Beijing central city which consists of six districts, as shown in the Figure 2, Dongcheng and Xicheng districts are classified as urban areas, the rest are classified as near suburban areas including Chaoyang, Haidian, Fengtai and Shijingshan districts.

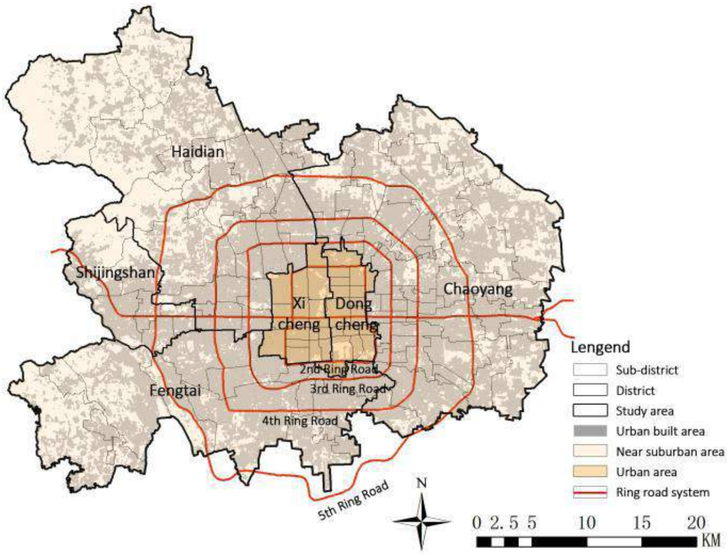
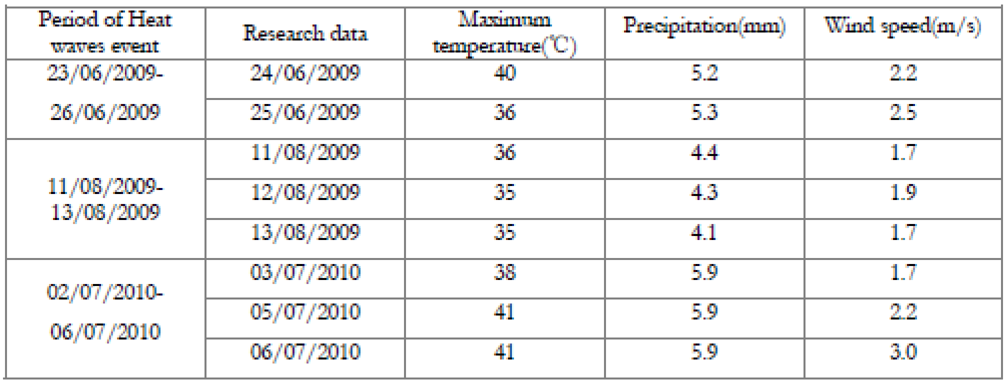


Figure 2 - Sub-districts of study area.
source: authors' elaboration

The central city, with an area of 1084 km2, covers 8% of the total administrative area of Beijing with 60% of Beijing’s total population. Due to the urban expansion from 2000 to 2010, there are a lot of farmlands outside 4th Ring Road are partly displaced by man-made land, which is also considered as the main reason of consistently aggravating UHI effect in Beijing. As a result, the risk in near suburban areas grows faster than other areas within the city (Dong and Liu et al., 2014). In addition to the high population density, Beijing’s aging population is expanding fast, which may also increase the potential risk for heat waves.

For the 1961-2010 period, air temperature in Beijing has risen by average 1.36℃ as a result of global warming and UHI effect. Recently the frequency of heat wave is continually increasing. The previous study demonstrated that more extreme high temperature events occurred in the Beijing′s urban areas than others (Zheng and Fan et al., 2006). In order to focus on the specific heat wave event, this study adopts the definition of heat waves from China Meteorological Administration(CMA), a period of more than three consecutive days in which daily maximum temperature exceeds 35℃, and selects three heat waves events in the summer of 2009 and 2010 year as research objects. Considering the requirement of similar weather during clear sky condition and quality of temperature data, the research data and weather conditions are shown as Table 1. In addition, the size of assessment unit is important for the final result. As the lowest level of administrative division and smallest unit of census in China, sub-district level plays fundamental role in mitigating the impacts of heat waves. Therefore, this study utilizes 129 sub-districts (not include the Capital Airport sub-district) to identify the spatial pattern of heat vulnerability.



Period of Heat waves event	Research data	Maximum temperature(℃)	Precipitation(mm)	Wind speed(m/s)
23/06/2009- 26/06/2009	24/06/2009	40	5.2	2.2
	25/06/2009	36	5.3	2.5
11/08/2009- 13/08/2009	11/08/2009	36	4.4	1.7
	12/08/2009	35	4.3	1.9
	13/08/2009	35	4.1	1.7
02/07/2010- 06/07/2010	03/07/2010	38	5.9	1.7
	05/07/2010	41	5.9	2.2
	06/07/2010	41	5.9	3.0

Table 1 - Weather condition of selected objects.
source: www.wunderground.com

4 INDEX SYSTEM

For the purpose of this study, UHV is viewed as a function of exposure to heat, sensitivity and adaptive capacity of people. Exposure is defined as the extent to which a system is subject to the geographical range of heat waves hazard; sensitivity is the degree to which a system is affected by heat waves based on the stability within the system; adaptive capacity describes the ability of a system to avoid and reduce the negative outcomes and impacts of heat wave. Thus, high magnitude of vulnerability to heat may results from high exposure, high sensitivity or low adaptive capacity. Based on this framework (Figure 3)and local characteristic of study area, twelve indicators are obtained from census data and remote sensing data. The source of census data includes 2008 Beijing Economic Census Yearbook and 2010 Beijing Population Census, remote sensing data is retrieved from MODIS and contemporaneous Landsat TM satellite images.

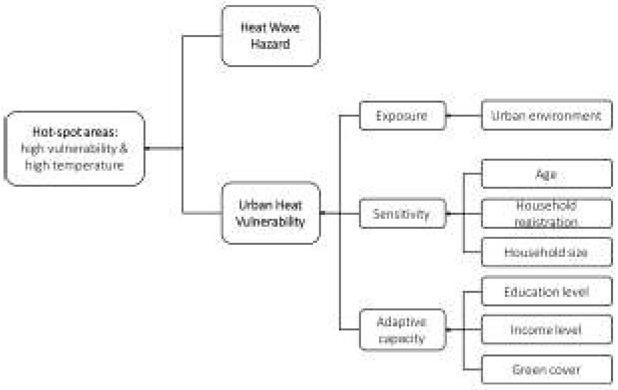


Figure 3 - Detailed flowchart of urban heat vulnerability assessment.
source: authors' elaboration

Within the framework, exposure to heat is affected by both indoor heat and outdoor heat, however there are not specific indicators to describe indoor thermal environment from census data. Thus, this study only focuses on the role of urban environmental characteristic in contributing to outdoor heat. Urban environmental characteristic is represented by the normalized difference building index(NDBI), nocturnal surface UHI effect and population density. The NDBI (MIR-NIR/MIR+NIR) is a measure to indicate the abundance of man-made land which is called as impervious surfaces. As shown in some studies, NDBI is used to be alternative indicator of land surface temperature(LST) because of the strong correlation between them. Recently UHI effect has been shown to interact with the high temperature in summer. Therefore, higher risk to heat is often within areas where has a long duration of high temperature all day. To make intra-urban difference in temperature more obvious, UHI effect is represented by nocturnal surface temperature derived from the LST products (MYD11A1) of MODIS satellite image. MYD11A1 product provides per-pixel temperature at 1km spatial resolution and includes daytime and nighttime LST retrieved by the split-window algorithm. Although LST can't be regarded as a direct observation on UHI, it has been demonstrated to be strongly related with air temperature during the clear sky condition. Compared with canopy UHI calculated by interpolation method, the measurement with remote sensing techniques can make the spatial distribution of surface UHI more consecutive. However, the cloud cover within study area can't make all selected objects (Table 1)available. Thus, nighttime LST products during the heat waves in 2010 (03/07/2010, 05/07/2010, 06/07/2010) are selected to present the nocturnal UHI effect. For the third indicator, population density within sub-district is one of indicator to measure urban density. Although the relation between population density and heat-related mortality is ambiguous (Johnson and Stanforth et al., 2012), the role of high population density in aggravating exposure to UHI effect and high temperature is identified among some studies (Tomlinson and Chapman et al., 2011; Romero-Lankao and Qin et al., 2012).

In the case of heat waves, sensitivity of people depends on some indicators that derive from heat-related mortality and scio-economic factors discussed in social vulnerability index (SoVI). Based on the previous studies, age, preexisting health condition and living alone are main contributors that influence the sensitivity to heat. In addition to these general indicators, scholars point that household-registration system, or hukou in Chinese, reinforce the inequalities in public service between immigrants and local inhabitants. Thus, four indicators are selected as representative: the percent of population older than 65 years or younger than 5 years, the percent of immigrants and the percent of population living alone .

Adaptive capacity has a strong influence on the vulnerability to heat. Quantitative and qualitative indicators are both utilized to present the awareness and practices toward the high temperature hazard, however, in this study, it's impossible to investigate this information within the large area. Thus, some alternative indicators are chosen to describe the education level, income level and green cover. The inhabitants with high education level can, to some degree, quickly response towards the current hazard and adopt the exact coping strategies, while some heat-related mortality are mainly attributed to the lack of risk awareness. Thus, low education level is represented by two indicators including the percent of population with education level lower than high school and the percent of illiterate in the population older than 15 years. Income level can indicate not only the economic status, but also the access to public service, thermal environment, dwelling types, the availability of cooling amenities and many characteristics related to that. In the study conducted by (Harlan and Brazel et al., 2006), the concentrated poverty areas are demonstrated to have higher temperature and less green cover than other communities. Although this phenomenon is not so acute in Beijing, income level plays a crucial role in capacity to adapt to heat waves. Due to no poverty populations or income data within sub-district level, the last three careers are defined as low-income ones based on the 2008 industrial wage ranking from 2009 Beijing statistical yearbook. In view of the employed population of farming, forestry, animal husbandry and fishery is negligible within Beijing's central city, thus corresponding groups engaged in resident service and accommodation & catering are considered to be in the low economic status. With respect to urban green space, it is considered as one of most efficient methods to ameliorate thermal environment. In the studies related cooling effect of urban green space, green coverage is found to have a negative correlation with ambient temperature around the green space. Therefore, this study utilizes green coverage within sub-district as indicator to represent the external resource for mitigating the heat risk. Green coverage is calculated by the dimidiate pixel model based on normalized difference vegetation index (NDVI), which is retrieved from contemporary Landsat TM satellite image.

5 METHODS

5.1 DATA PROCESSING

Due to the difference between the dimension of data, these indicators should be firstly normalized by range standardization method. With respect to the negative or positive correlation (Table 2) between indicator and component, for example, adaptive capacity will decrease when employment population of accommodation & catering increase. Thus, positive standardization equation (II) and negative standardization equation (III) are shown as following. Before indicators are normalized, an m x n matrix X (I) is composed of individual items x_{ij}.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \qquad \text{(I)}$$

$$X_{ij} = \frac{x_{ij} - \min_j\{x_{ij}\}}{\max_j\{x_{ij}\} - \min_j\{x_{ij}\}} \qquad \text{(II)}$$

$$X_{ij} = \frac{\max_j\{x_{ij}\} - x_{ij}}{\max_j\{x_{ij}\} - \min_j\{x_{ij}\}} \qquad \text{(III)}$$

Where:

xij refers to the original value at the ith sub-district and jth indicator (i=1,2,...,m; j=1,2,...,n);

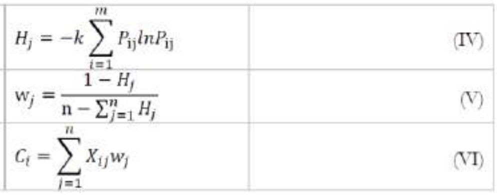
m refers to the number of sub-districts, n refers to the number of indicators within each component;

Xij refers to the normalized value of xij;

max$\{xij\}$ refers to the maximum among the original value, min$j\{xij\}$ refers to the minimum among the original value.

5.2 WEIGHTING METHOD

The approach to determine the weight of indicators consists of subjective weighting method and objective weighting method, both of which are widely used in the statistic analysis. As one of the objective weighting methods, entropy weight method is utilized to calculate the weight of indicators within each component in this study. Entropy is originally described as a disordered and chaotic state in the thermodynamics. After Shannon introduced this concept into information theory, entropy represented the uncertainty of information. Because the utility of information is negatively correlated with the uncertainty of information, entropy-weight determines the relative weight among indicators.



$H_j = -k\sum_{i=1}^{m} P_{ij} ln P_{ij}$	(IV)
$w_j = \frac{1 - H_j}{n - \sum_{j=1}^{n} H_j}$	(V)
$C_i = \sum_{j=1}^{n} X_{ij} w_j$	(VI)

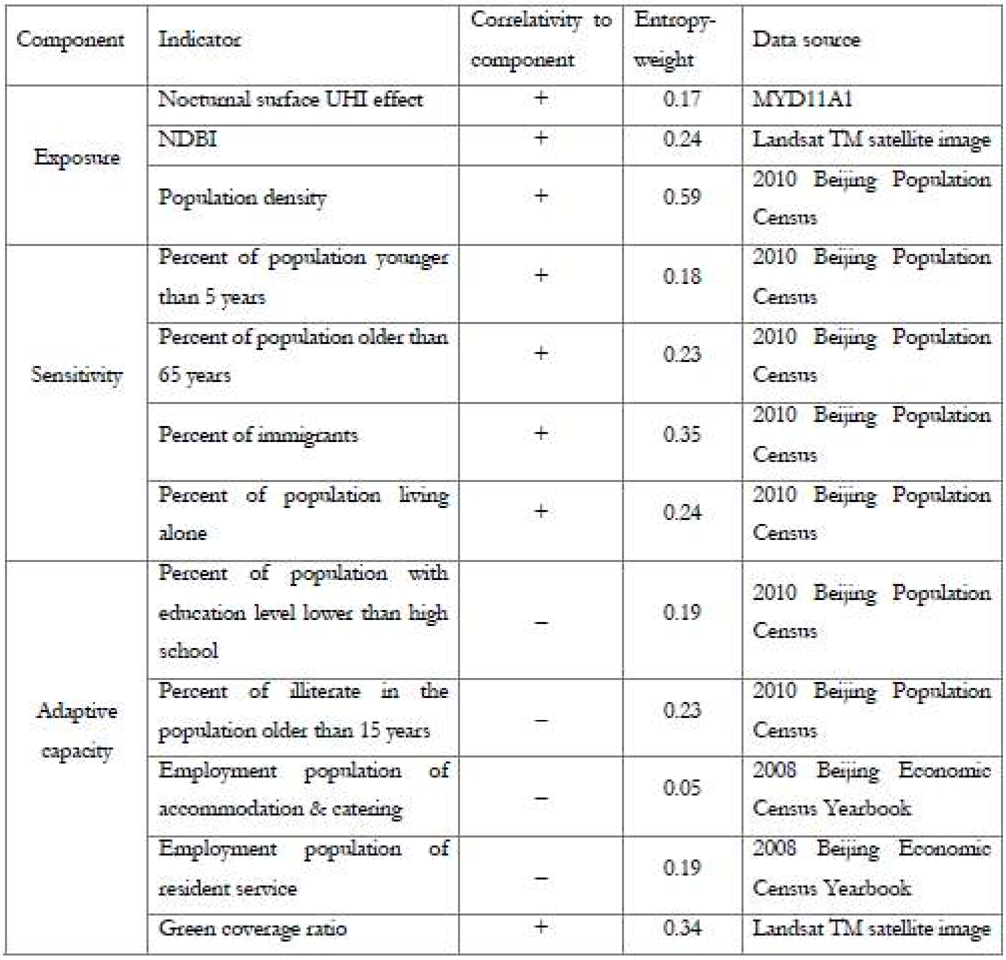
Where:

Pij refers to the proportion of Xij in the sum of all sub-districts' value at jth indicator, Pij=$Xij\sum Xijmi$=1⁄,k=1/ln$m$,when Pij=0, PijlnPij=0;

Hj refers to the entropy of each indicator within the component;

wj refers to the entropy-weight within each component;

Ci refers to the value of each component.



Component	Indicator	Correlativity to component	Entropy-weight	Data source
Exposure	Nocturnal surface UHI effect	+	0.17	MYD11A1
	NDBI	+	0.24	Landsat TM satellite image
	Population density	+	0.59	2010 Beijing Population Census
Sensitivity	Percent of population younger than 5 years	+	0.18	2010 Beijing Population Census
	Percent of population older than 65 years	+	0.23	2010 Beijing Population Census
	Percent of immigrants	+	0.35	2010 Beijing Population Census
	Percent of population living alone	+	0.24	2010 Beijing Population Census
Adaptive capacity	Percent of population with education level lower than high school	–	0.19	2010 Beijing Population Census
	Percent of illiterate in the population older than 15 years	–	0.23	2010 Beijing Population Census
	Employment population of accommodation & catering	–	0.05	2008 Beijing Economic Census Yearbook
	Employment population of resident service	–	0.19	2008 Beijing Economic Census Yearbook
	Green coverage ratio	+	0.34	Landsat TM satellite image

Table 2 - Weights of indicators within each component.
source: authors' elaboration

5.3 VULNERABILITY SCORING

For the purpose of identifying the intra-urban variation and spatial distribution of UHV, sub-district scores of heat vulnerability (V) are calculated by following assessment equation (VII) where E=exposure to heat, S=sensitivity and A=adaptive capacity.

Although some previous studies adopted statistic method, such as principle component analysis (PCA) or analytic hierarchy process (AHP) to weight among components, the acknowledged relationship between components is still need to demonstrate, meanwhile, in addition to the evaluating scores from experts, the important roles of inhabitants and policy makers in determining the weight need further to be strengthen. Thus, this study utilizes equal weight to integrate these three components.

Because the threshold of heat wave are defined as air temperature, the trasformation from diurnal LST into air temperature need to be calculated by the means of the relation equation (VIII),which R2 is up to 0.797(Li,2013).

$$V = E + S - A \qquad \text{(VII)}$$

Where:

T refers to the air temperature;

TLS refers to the diurnal land surface temperature during heat wave.

According to the calculation result, the surface temperature is approximately 45.1℃ when air temperature reaches 35℃. Because the time that diurnal temperature data of MODIS image collected is belongs to the period of maximum of air temperature one day, the areas that temperature exceeds 45.1℃ are thought to be suffering from the impact of heat wave hazard. Thus, this study calculates the average value of LST within each sub-district and then select sub-districts with a surface temperature of 45.1℃ and higher to form the heat wave hazard layer.

6 RESULTS

In order to present the intra-urban variant score of sub-districts clearly, five classes are categorized by natural breaks (Jenks) method in ArcGIS 10.3. In this section, results of single component and composite map will be presented and discussed.

According to the spatial pattern of exposure in the study area (Figure 4), sub-districts located in the city center are at high and very high level, as the distance from the city center increased, the score of exposure goes up and then down. In contrast with the highly centralized pattern of exposure score within western cities, there are some sub-districts with low level located in the Beijing's center area. It may be attributed to the presence of large open spaces, including the Forbidden city, Temple of Heaven park and Beihai park, which inhibits the continued increase of exposure to heat. The sub-districts with the very high level, comprising 25 sub-districts, are scattered throughout the city center. These areas are where many communities clustered, including newly-built type with high-volume and old one with high-density.

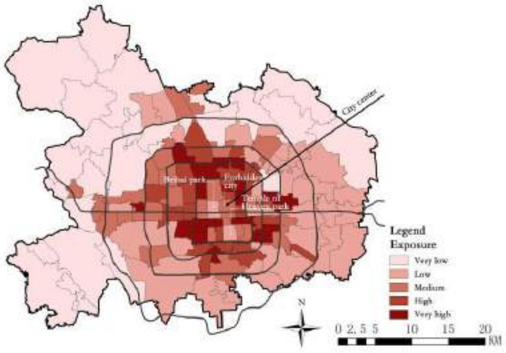


Figure 4 - Sub-districts scores of exposure.
source: authors' elaboration

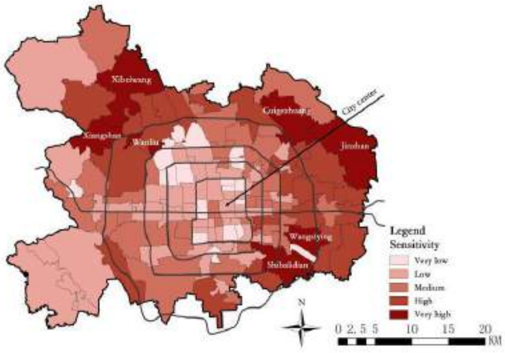


Figure 5 - Sub-districts scores of sensitivity.
source: authors' elaboration

According to the distribution of scores of sensitivity (Figure 5), the spatial pattern of sensitivity is utterly different from that of exposure. Sub-districts with high and very high level are located in the near suburban areas rather than city center. The ones with very high level, comprising Wanliu(0.634), Wangsiying(0.620), Cuigezhuang(0.617), Xiangshan(0.571), Jinzhan(0.555), Xibeiwang(0.553) and Shibalidian(0.549), form three high-score clusters. In general, these three clusters highly concentrated sensitive people are all typical areas in urban-rural fringe, which representing both urban and rural feathers.

Finally, significant concentration in the distribution of human's adaptive capacity is located in the northern part within the study area. The twelve sub-districts with very high level comprise Qinghuayuan(0.846), Yanyuan(0.815), Aoyuncun(0.776), Datun(0.772), Zizhuyuan(0.759), Qinglongqiao(0.758), Xueyuanlu(0.753), Donghu(0.747), Wanliu(0.733), Shangdi(0.730), Haidian(0.719) and Xiangshan(0.715). The concentration of the best education resource and high-skilled employments appeals for many high-class and middle-class residents to live around. Besides, the large parks and natural landscape, owned by Aoyuncun, Xiangshan and Qinglongqiao sub-districts, play a important role in alleviating the thermal environment.

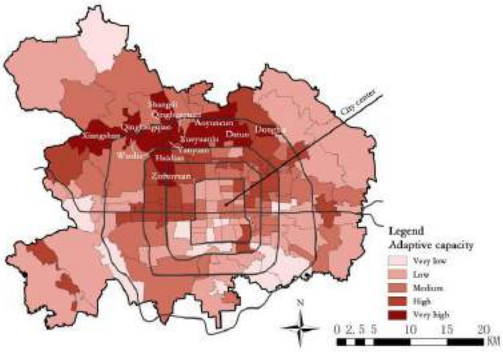


Figure 6 - Sub-districts scores of adaptive capacity.
source: authors' elaboration

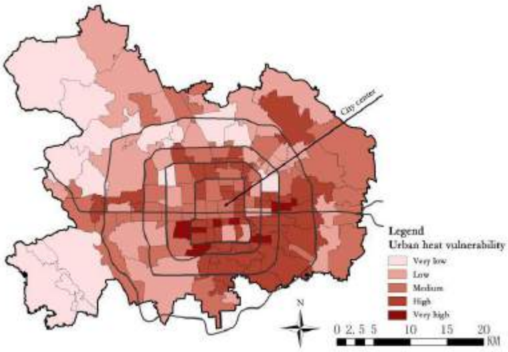


Figure 7 - Intra-urban variation of urban heat vulnerability.
source: authors' elaboration

Figure 6 shows that the "very high" vulnerable sub-districts are scattered throughout the city center and the "high" vulnerable sub-districts are located in the southeastern part of study area, where the high exposure is experienced as well as high sensitivity and low adaptive capacity. The histogram (Figure 7) also indicates that the majority of "very high" vulnerable sub-districts are located in the Xicheng and Chaoyang district, while the percent of the "high" vulnerable sub-districts in Chaoyang district is higher than others. The "low" and "very low" vulnerable sub-districts are mainly concentrated in the Haidian district.

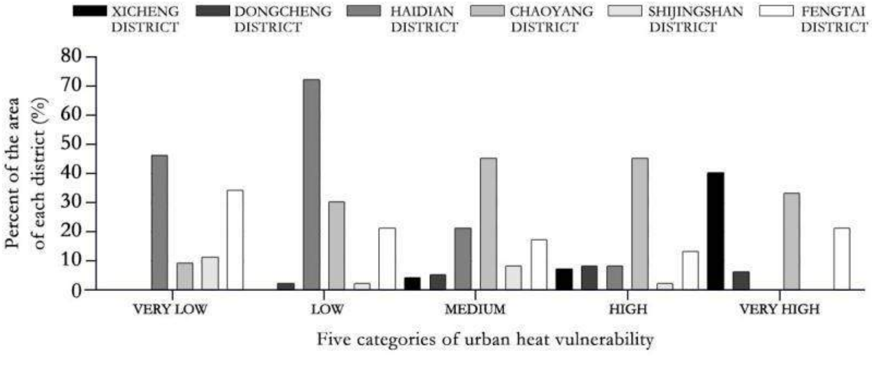


Figure 8 - The area percent of each district in the five categories.
source: authors' elaboration

The Pearson correlation coefficient is carried out to determine the relationship between temperature and the UHV. The result shows that the coefficient reaches up to 0.581 ($p<0.01$). In order to identify the hot-spot areas, where high vulnerability co-occurs with high intensity of heat wave, the "very high"vulnerable sub-districts, as well as “high”vulnerable sub-districts, are respectively overlaid on the heat wave hazard layer. The hot-spot areas are divided into two categories. The “very high”vulnerable sub-districts with LST higher than 45.1 ℃ are ranked as the most important hot-spot areas, which comprising Guanganmenwai, Niujie, Youanmen, Dashilan and Chongwenmenwai. Thus, the identified hot-spot areas should be considered as priorities areas for the implementation of adaptive planning.

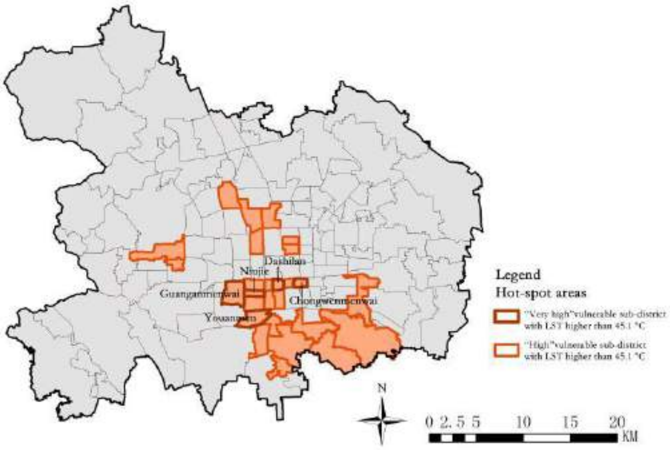


Figure 9 - Hot-spot areas.
source: authors’ elaboration

7 PLANNING STRATEGIES FOR HEAT WAVE

In order to cope with uncertainties of climate change by means of urban planning, adaptive strategies should focus both on the pre-disaster prevention and post-disaster mitigation. The hot-spot areas can be utilized to form the priority in implementing adaptive planning. For the specific strategies in the priority area, this study presents the potential ways as following.

Urban design plays the important role in regulating urban micro-climate conditions (Golany,1996). In order to enhance the effect in alleviating the thermal environment, the specific strategies are presented in following three spatial scales. At the city scale, urban design should be integrated with the meteorological data to set up hierarchical ventilation corridors which can facilitate air flow; at the neighborhood scale, the contribution of different physical factors in impacting on air temperature should be identified, then based on the simulation with different combinations of identified factors, the efficient strategy on the cooling effect is presented; at the building scale, the principles of green building and low-carbon building should be implemented in all kinds of buildings as much as possible. Compared with urban and building scale, the cooling effect at the neighborhood scale is easy to perceive and operate. Taking into account the characteristics of physical environment, the planner or policy maker should develop variant plannings at the neighborhood scale, in the sub-district with high proportion of impervious surface and low building density, increasing the area of vegetable cover may be the most efficient way, however, in the sub-district with high building density, the design strategies may be mainly focused on the improvement of cooling effect (Norton and Coutts et al., 2015). Although urban design for prevention can reduce the intensity and frequency of heat wave in some degree, it is impossible to avoid the advent and impacts of heat wave fundamentally. Thus, the seasonable response during the heat wave is equally important. The accessibility to the hospitals and other medical resources within the hot-spot areas should be the first focus of mitigation strategies.

8 CONCLUSION

The study presents a method for quantifying urban heat vulnerability at the sub-district scale in Beijing central city. The result shows that “very high” and “high” vulnerable sub-districts are located in the city center and southeastern part of study area, which means the uneven impacts of heat wave event. By overlaying between heat vulnerability and heat wave hazard, the five sub-districts, which are considered as the most important hot-spot areas, are identified to be the priority areas in adaptive planning. In terms of the specific implementation of adaptive planning , urban design for prevention and accessibility planning for mitigation are the potential ways. However, before applied into practice, the assessment of urban heat vulnerability and the effect of such strategies are still need to be further tested. This will be the focus of future work.

ACKNOWLEDGMENT

The author would like to acknowledge the Natural Science Fund of China (51408332) and the Project of Humanities and Social Sciences of the Ministry of Education (No. 14YCZH140), which collectively funded this project.

BIBLIOGRAPHIC REFERENCES

IPCC. (2014). Climate Change 2014: Synthesis Report. http://www.ipcc.ch/pdf/ assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf.

Yang, X. C., Chen, B. D., Hu, K. J. (2015). A review of impacts of urbanization on extreme heat events. PROGRESS IN GEOGRAPHY, 34(10), 1219-1228. in Chinese.

Harlan, S. L., Brazel, A. J., Prashad, L., Stefanov, W. L., & Larsen, L. (2006). Neighborhood microclimates and vulnerability to heat stress. Social science & medicine, 63(11), 2847-2863.

Wilhelmi, O. V., Purvis, K. L., & Harriss, R. C. (2004). Designing a geospatial information infrastructure for mitigation of heat wave hazards in urban areas. Natural Hazards Review, 5(3), 147-158.

GCCA. (2014). Cool Policies for Cool Cities: Best Practices for Mitigating Urban H-eat Islands in North American Cities. http://www.coolrooftoolkit.org/ wp-content/uploads/2014/06/ACEEE_GCCA-UHI-Policy-Survey-FINAL.pdf.

Birmingham city council. (2012). Climate Change Adaptation Action Plan 2012+. http://www.bebirmingham.org.uk/uploads/BCCAAP_final.pdf.

NCCARF. (2013). A spatial vulnerability analysis of urban populations during extreme heat events in Australian capital cities. http://apo.org.au/files/R-esource/Loughnan-ExtremeHeatEventsinAustralianCapitalCities.pdf.

Moreland city council. (2016). Moreland Urban Heat Island Effect Action Plan.http://www.moreland.vic.gov.au/globalassets/areas/esd/esd-uhie-urban-heat-i-sland-effect---action-plan---final-draft-for-council-june-2016.pdf.

Brooks, N. (2003). Vulnerability, risk and adaptation: A conceptual framework. Tyndall Centre for climate change research working paper, 38, 1-16.

Lindley, S. J., Handley, J. F., Theuray, N., Peet, E., & McEvoy, D. (2006). Adaptation strategies for climate change in the urban environment: assessing climate change related risk in UK urban areas. Journal of Risk Research, 9(5), 543-568.

Tomlinson, C. J., Chapman, L., Thornes, J. E., & Baker, C. J. (2011). Including the urban heat island in spatial heat health risk assessment strategies: a case study for Birmingham, UK. International journal of health geographics, 10(1), 42.

Allen, K. (2003). Vulnerability reduction and the community-based approach. Natural disasters and development in a globalizing world, 170.

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. Social science quarterly, 84(2), 242-261.

Reid, C. E., O'Neill, M. S., Gronlund, C. J., Brines, S. J., Brown, D. G., Diez-Roux, A. V., & Schwartz, J. (2009). Mapping community determinants of heat vulnerability. Environmental health perspectives, 117(11), 1730.

Wolf, T., & McGregor, G. (2013). The development of a heat wave vulnerability index for London, United Kingdom. Weather and Climate Extremes, 1, 59-68.

Harlan, S. L., Declet-Barreto, J. H., Stefanov, W. L., & Petitti, D. B. (2013). Neighborhood effects on heat deaths: social and environmental predictors of vulnerability in Maricopa County, Arizona. Environmental Health Perspectives (Online), 121(2), 197.

Maier, G., Grundstein, A., Jang, W., Li, C., Naeher, L. P., & Shepherd, M. (2014). Assessing the performance of a vulnerability index during oppressive heat across Georgia, United States. Weather, climate, and society, 6(2), 253-263.

Johnson, D. P., Stanforth, A., Lulla, V., & Luber, G. (2012). Developing an applied extreme heat vulnerability index utilizing socioeconomic and environmental data. Applied Geography, 35(1), 23-31.

IPCC. (2001). Climate Change 2001: Impacts, adaptation, and vulnerability.https://gridarendal-website.s3.amazonaws.com/production/documents/:s_document/290/original/wg2ts.pdf?1488203667.

Wilhelmi, O. V., & Hayden, M. H. (2010). Connecting people and place: a new framework for reducing urban vulnerability to extremeheat. Environmental Research Letters, 5(1), 014021.

Dong, W., Liu, Z., Zhang, L., Tang, Q., Liao, H., Li, X. E. (2014). Assessing heat health risk for sustainability in Beijing’s urban heat island. Sustainability, 6(10), 7334-7357.

Xie, P., Wang, Y., Liu, Y., Peng, J.. (2015). Incorporating social vulnerability to assess population health risk due to heat stress in China[J]. Acta Geographica Sinica, 70(7):1041-1051. in Chinese.

Zheng, Z. F., Fan, S. Y., Wang, Y. C. (2006). Effects of urban heat island on summer high temperatures in Beijing. Journal of Applied Meteorological Science, 17, 48-53. in Chinese.

Romero-Lankao, P., Qin, H., & Dickinson, K. (2012). Urban vulnerability to temperature-related hazards: A meta-analysis and meta-knowledge approach. Global Environmental Change, 22(3), 670-683.

Golany, G. S. (1996). Urban design morphology and thermal performance. Atmospheric Environment, 30(3), 455-465.

Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Landscape and Urban Planning, 134, 127-138.

ID 1630 | PARTICIPATORY MODELLING TO SUPPORT GROUP DECISION MAKING PROCESSES IN CLIMATE RESILIENT URBAN DESIGN

Linda Nijland[1]
[1]Radboud University
l.nijland@fm.ru.nl

1 INTRODUCTION

Interest in climate resilience is growing worldwide among policy makers, urban planners, citizens and scientists. Climate Resilient Urban Design (CRUD) relates to the (re-)design of urban areas in such a way that cities and citizens become less vulnerable to climate change. Weather phenomena like heat stress, droughts and floods impact the lives of city dwellers, villagers, and rural residents all over the globe. The making of policies dealing with climate resilience in urban environments is a process that inevitably involves stakeholders from various disciplines, each with their own interests, constraints and goals.

Group Model Building (GMB) (Vennix, 1999) is known to facilitate the decision making processes by modelling important variables and their causal relations in a Causal Loop Diagram (CLD). This participatory group modelling process creates a shared understanding of the problem, incorporating the views of all stakeholders, and it improves the support for the final decisions taken.

The GRACeFUL (Global systems Rapid Assessment tools through Constraint Functional Languages) project aims at supporting decision making in complex problems by connecting participatory processes (using GMB) to scientific evidence through novel tools. Rapid Assessment Tools typify causal factors and linkages with concrete data from other system layers and produce a set of viable and acceptable alternative solutions to be used in decision making. Simulation tools will simulate the alternative scenarios over time and visualization tools will show the results of the different CRUD solutions on maps. The case study area is a neighbourhood in the city of Dordrecht, the Netherlands. The municipality is planning to redevelop the public space in this neighbourhood taking into account climate resilience and involving different stakeholders, including citizens.