Assessment of human heat vulnerability of different Local Climate Zones in Lahore

Coupling remote sensing and socioeconomic data

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***Abstract*—High population influx and rapid urban growth have not only amplified extreme weather events but also have significantly influenced the sustainable development of cities. Therefore, urban planning must account for urban transformation and extreme events as efficiently as possible. Using the concept of a human-environment system, this study proposes a practical approach for the assessment of human vulnerability to heat stress in different Local Climate Zones (LCZs) of Lahore. Using the human vulnerability index computed at the union council administrative scale and LCZs data at 100m cell size, GIS tools (i.e. rasterization and zonal statistics) are used to compare the datasets. The linkage of human heat vulnerability with LCZs shows that human vulnerability is relatively low in compact development compared to sparsely built-up and low-density areas. It is due to the income profile of residents as well as accessibility of social infrastructure in compact development zones. This assessment of cross-scale mechanisms of human heat vulnerability in urban systems is expected to inform policymakers and stakeholders in developing effective policies to address social, economic, and health risks.**

Keywords—human vulnerability, Local Climate Zones, spatial analysis, climate change adaptation

I. INTRODUCTION

As climate change continues over decades, urban areas are particularly expected to be hit by global warming [1–3]. The risks related to increased anthropogenic emissions from industrial activities, increased traffic, electricity and heat generation are not restricted to urban centers but it has also posed an unavoidable threat to the well-being and health of global human populations [4–7]. Urban heat islands (UHIs) are exacerbating the effects of global warming on local climates, especially in cities[9]. In urban areas, heatwaves frequency coupled with UHI effect exacerbate thermal conditions [10,11]. As a result, the mortality risk during heat waves has increased particularly among the old age population [12,13].

Distinct morphology and physical structures influence the thermal stresses, and consequently, the associated risk of heat stress in cities [14–16]. Various studies have been conducted around the globe for understanding the association between urbanization and UHI [17,18]. It is established that densely built cities present high differences in UHI and pose high heat risks, which vary within urban areas. However, such analysis involves a wide-ranging land cover and urban form data for the classification of urban areas, which vary largely from one region to another [19]. In this regard, Stewart and Oke (2012) presented the concept of a "Local Climate Zones (LCZs)", which refer to "the region of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometers in the horizontal scale" (p. 1884). An understanding of LCZs in a city can assist with estimating the surface thermal characteristics, energy consumption, and heat risk [14]. Interestingly, this LCZs and urbanization nexus is mostly studied in terms of how exposed LCZs are to, for instance, heat risk [14,15,19]. However, this interdependence goes further than the state of the art [20]. The significance of population profile and their attributes such as age, income, education, health etc. cannot be ignored, as individuals living in a same location may not be equally susceptible [4,5,21,22].

Exploring intra-city disparity concerning human dynamics begins with the vulnerability assessment. It is important to comprehend the spatial settings within urban areas in which these disparities originate given the diversity of socio-physical elements found in the cities [23]. In this regard, vulnerability assessment using index based approaches provide a snapshot of where vulnerable hotspots occur in a city at a particular administrative scale. However, it is challenging to develop specific adaptation measures due to lack of information about urban fabric and neighborhood morphology. Moreover, given the fact that socioeconomic (age, health, income etc.) and physical data (building height, vegetation density etc.) is not always available at same spatial scale so it is difficult to examine the interlinkages between both. Following the discussion, these research questions are posed and addressed for the case study area of Lahore, Pakistan.

How can different spatial scales be coupled in terms of socioeconomic (i.e. human heat vulnerability) and remote sensing data (LCZs classification)?

How does human heat vulnerability vary in different LCZs and what are the interlinkages between the human heat vulnerability index and LCZs classes?

II. MATERIAL AND METHODS

A. Study area

The study area is the metropolitan city Lahore, which is second-biggest city of Pakistan inhabiting more than 12 million people [25]. The city covers an area of 1772 km^2 and is quite heterogeneous in terms of growth pattern and socioeconomic condition across its nine administrative districts [25]. Rapid urbanization, followed by dominantly horizontal expansion, has characterized the development dynamics of the city in recent years. According to the Urban Unit, the built-up area of Lahore almost doubled between 2005 and 2017, with a growth rate of 7.1% [26]. With a mix of high to medium dense and sparsely developed areas, Lahore displays high spatial heterogeneity in development dynamics [28]. The city has witnessed various climate-induced hazard events, including heat waves, heavy precipitation, and flash floods. However, the climate conditions of the region along with various environmental stressors have intensified the impacts of heat waves. In June 2019, a record-breaking high temperature of 46°C was reported. Moreover, in July 2021, the temperature reached around 44°C. Likewise, heatwaves became 100 times more likely in summers 2022 [29] which are affecting the health and daily lives of the residents.

B. Data collection and processing

We have categorized our analysis to study interlinkages between different LCZs and their human heat vulnerability in Lahore into three steps. The first step is the collection of data. Data regarding LCZs is obtained where a Standard WUDAPT methodology is used for mapping LCZs in Lahore. A comprehensive methodology for mapping LCZs in Lahore can be found in this reference [27]. On the other hand, for the assessment of human heat vulnerability, various demographic and socioeconomic factors are aggregated and an index is computed using a weighted sum. A detailed description of the indicators used and their computation method can be seen in this reference [30]. The second step relates to the preprocessing and transformation of data to ensure consistency for interlinking. In this respect, the human heat vulnerability index has been normalized using the min-max transformation and divided into five quantiles that span from very low to very high vulnerability levels. LCZs data is classified into 16 standard classes. It is important to mention that LCZ class 1, i.e. compact high-rise is not likely to occur in Lahore as per data and knowledge about the city [27]. Figure 1 presents the collected and preprocessed data regarding heat vulnerability and LCZs for Lahore.

Human vulnerability is computed at union councils (UCs) scale, which is the smallest administrative scale for Lahore case. Contrarily, LCZs are obtained using the resampling of raster data at 100 m cell size. Thus, it is quite challenging to bring both administrative and remote-sensing scales together for comparison. In this respect, the second step involves the rasterization of vector data i.e. human vulnerability index. The polygon to raster tool is used for this purpose. Cell size and processing extent are used the same as the LCZs layer. Finally, using the zonal statistic tool in GIS the relative heat vulnerability in different LCZs is explored and descriptive statistics i.e. mean, standard deviation, and percentiles are exported using zonal statistics as a table tool. Moreover, human vulnerability is compared only in built-up area classes in LCZs.

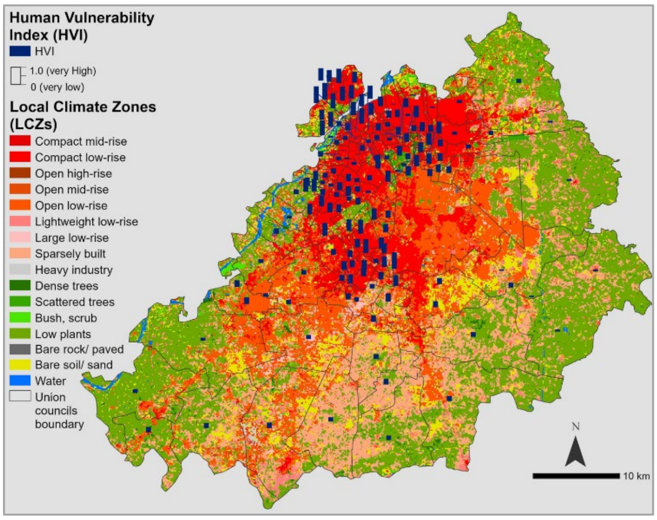


Figure 1. *Relative human heat vulnerability map at UCs administrative scale and LCZs in study area. Source: Own presentation based on Iqbal et al. 2022; Aslam et al. 2022*

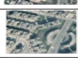
III. RESULTS

In the following section, the results captured from the assessment of human vulnerability for different LCZs in the study area are presented and associated descriptive statistics are explained to examine the linkage between both.

Human vulnerability in different LCZs

Overall, human heat vulnerability is high in different built-up classes of LCZs in Lahore. Table 1 presents the descriptive statistics of human vulnerability in different built-up classes. It is interesting to monitor that the people living in compact low-rise and mid-rise development are comparatively less vulnerable to heat stress. In this regard, compact mid-rise (LCZ 2) development is distributed within the city in smaller segments, for instance, Askari 11 (sector B), and Quaid Housing Scheme fall into this category (see Figure 2). These are formally developed areas with a high to middle income group of people. Such socioeconomic conditions reduce vulnerability levels in these LCZs.

TABLE 1. DESCRIPTIVE STATISTICS OF HUMAN VULNERABILITY TO HEAT STRESS IN BUILT-UP LCZS

LCZs BUILT-UP CLASSES		MIN	MAX	RANGE	MEAN	STANDARD DEVIATION
Compact mid-rise (LCZ 2)		0,00	1,00	1,00	0,51	0,20
Compact low-rise (LCZ 3)		0,00	1,00	1,00	0,50	0,22
Open high-rise (LCZ 4)		0,46	0,81	0,35	0,51	0,12
Open mid-rise (LCZ 5)		0,17	0,94	0,77	0,55	0,11
Open low-rise (LCZ 6)		0,00	1,00	1,00	0,54	0,13
Lightweight low-rise (LCZ 7)		0,00	1,00	1,00	0,53	0,13
Large low-rise (LCZ 8)		0,00	1,00	1,00	0,56	0,12
Sparsely built (LCZ 9)		0,04	1,00	0,96	0,58	0,09
Heavy industry (LCZ 10)		0,17	0,92	0,75	0,59	0,12

Visual representation of the LCZs in Lahore is drawn from Google Earth.

Next to that, compact low-rise (LCZ 3) development is most prominant development typology in the study area. Central areas of the city including the Walled City, Gulshan-e-Ravi, and Model Town are mostly compact low-rise. In this class, the mean vulnerability to heat stress is 0.50 that is comparatively lower than other zones. However, the standard deviation in mean vulnerability is noticeably higher (see Table 1). The areas that fall under this category have been developed both formally and informally. In planned compact zones, vulnerability is low due to the socioeconomic profiles of people as well as access to social infrastructure in comparison to unplanned (informal) areas. Resutantly, standard deviation in vulnerability is higher in this class.

On the other hand, open high-rise and mid-rise zones are found less dominant in the city and mostly newly developed housing areas in southern and eastern parts of the city fall into this category (see Figure 2). Overall, the mean vulnerability in these areas is comparatively higher. Open low-rise development (LCZ 6) is the second most prevalent LCZs class in Lahore. It covers the areas including railway flats present in the central part, Shuhada Town situated in the city outskirts, and some commercial zones. Mean human vulnerability in this climate zone is relatively high (0.54). It is because these are the areas majorly hit by the recent high growth trends and residents of these areas have less coping and adaptive capacities.

Large low-rise (LCZ 7), lightweight low-rise (LCZ 8), and sparsely built-up (LCZ 9) settlements are found mostly in the suburbs of the study area. It can be seen that human vulnerability is very high in these areas with a mean value of 0.58. In addition, the standard deviation is relatively low in these climate zones. The development typology of these zones is also both formal and informal. Nevertheless, they shared a common trait of urban transformation i.e. urban growth as a result of migration of people from nearby areas. This sprawl growth not only increases their susceptibility to heat stress but also puts immense pressure on the existing urban fabric concerning access to social infrastructure.

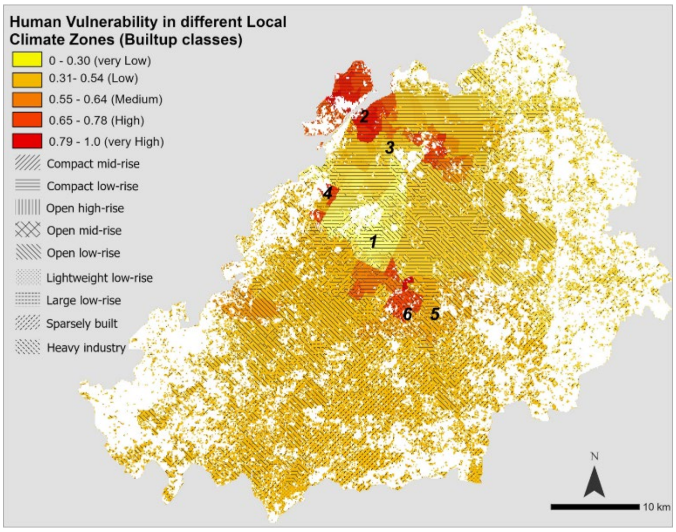


Figure 2. *Human vulnerability to heat stress in built-up LCZs (Numbers are presenting the areas as follows: 1-Model Colony, 2-Walled City, 3-Railway Flats, 4-Gulshan-e-Ravi, 5-Askari 11 (sector B), and 6-Quaid Housing Scheme)*

IV. Discussion and Conclussion

Human vulnerability assessment considering LCZs data can facilitate the identification of specific adaptation requirements of different urban zones in terms of heat stress. However, only a few studies interlink the vulnerable hotspots with LCZs [14,15,19]. It has been found that these studies mainly focus on physical and metrological interdependence instead of human dynamics. However, several studies underscore the importance of population profiles and socioeconomic factors for adaptation planning [24,30]. This study attempts to bring the human dimension into focus while analyzing LCZs.

Analysis of vulnerability in built-up categories of LCZs provided interesting insights. It is evident from the analysis that overall, mean human vulnerability to heat stress is comparatively low in compact development. However, the standard deviation is relatively higher across this zone. This zone covers different types of urban fabric including old city areas in the northern part (walled city) and formally developed areas (Model town and Askari) towards central areas. Due to the fact that the income factor is greater in the formally developed areas and access to socio-physical infrastructure is higher, people are less vulnerable to heat stress. In this respect, Lemonsu et al. 2015 argued that the compact city, because of its dense urban form, provides solar protection by reducing the penetration of the incoming solar radiation, it is efficient in alleviating urban heat islands during the day. However, contrary to Cai et al. 2019 and Zhou et al. 2021 who indicated that thermal stress and heat exposure are higher in compact high-rise development, this study illustrates that people are less susceptible and can cope with heat stress in the more compact zone in the Lahore context.

Nevertheless, human vulnerability fluctuates moving towards open low-rise climate zone. This climate zone is most prevalent in the case of Lahore and formed as the result of the current development trend i.e. reduction in the vegetation cover because of rapid transition into built-up areas, thus modifying the thermal conditions of the city. These areas mainly characterize new both formally and informally developed urban fabric. Although, in some of the planned areas people are less susceptible to heat stress but they have less capacity to cope [30]. Most importantly, it is evident from the analysis that in sparsely built-up areas, human vulnerability increased dramatically, and mean human vulnerability is very high. Rapid urban growth due to higher in-migration from nearby towns and villages resulted in a rapid increase in vulnerability in the climate zones. Frenkel and Ashkenazi 2008 and Ribeiro 2021 also highlighted how urban slums are increasing urban heat risk and putting immense pressure on services and infrastructure demand.

Overall, this paper attempts to use cell size derived from LCZs classified units instead of typical administrative units i.e., union council as a spatial scale for the computation of human vulnerability. Variation in the human vulnerability levels can be seen in different climate zones both statistically and geographically. Therefore, the methodology of coupling socio-economic and physical data is transferable to other regions depending upon the availability of data. Moreover, results derived from the analysis are applicable to other regions with similar development typologies and growth pattern i.e. rapidly transforming cities in Southeast Asia. Resultantly, micro-scale assessment can enable urban policy makers to address adaptations needs of people more holistically.

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REFERENCES

1. Tollefson, J. Climate change is hitting the planet faster than scientists originally thought. *Nature* **2022**, doi:10.1038/d41586-022-00585-7.
2. *Global Warming of 1.5°C;* IPCC, Ed.; Cambridge University Press, 2022, ISBN 9781009157940.
3. Lavell, A.; M. Oppenheimer, C.D.; J. Hess, R.L.; J. Li, R., Muir-Wood; S., M. *Climate Change: New Dimensions in Disaster Risk, Exposure, Vulnerability, and Resilience*: *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC).* 25-64, Cambridge University Press, Cambridge, UK, and New York, NY, USA, 2022. Available online: https://www.ipcc.ch/site/assets/uploads/2018/03/SREX-Chap1_FINAL-1.pdf.
4. Birkmann, J.; Liwenga, E.; Pandey, R.; Boyd, E.; Djalante, R.; Gemenne, F. *Poverty, Livelihoods and Sustainable Development*: *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK and New York, NY, USA, 2022. Available online: https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_Chapter08.pdf (accessed on 9 August 2022).
5. Gensuo, J.; Shevliakova, E. *Land–climate interactions. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*, 2019.
6. Tollefson, J. IPCC climate report: Earth is warmer than it's been in 125,000 years. *Nature* **2021**, *596*, 171–172, doi:10.1038/d41586-021-02179-1.
7. IPCC, 2. Climate Change 2014 : Synthesis Report: Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *undefined* **2014b**, 151.
8. *IPCC WGII Sixth Assessment Report*: *Summary for policy makers;* IPCC, Ed.; Intergovernmental Panel on Climate Change, 2022.
9. Soltanifard, H.; Aliabadi, K. Impact of urban spatial configuration on land surface temperature and urban heat islands: a case study of Mashhad, Iran. *Theor Appl Climatol* **2019**, *137*, 2889–2903, doi:10.1007/s00704-018-2738-4.
10. Chrysoulakis, N.; Grimmond, S.; Feigenwinter, C.; Lindberg, F.; Gastellu-Etchegorry, J.-P.; Marconcini, M.; Mitraka, Z.; Stagakis, S.; Crawford, B.; Olofson, F.; et al. Urban energy exchanges monitoring from space. *Sci. Rep.* **2018**, *8*, 11498, doi:10.1038/s41598-018-29873-x.
11. Bek, M.A.; Azmy, N.; Elkafrawy, S. The effect of unplanned growth of urban areas on heat island phenomena. *Ain Shams Engineering Journal* **2018**, *9*, 3169–3177, doi:10.1016/j.asej.2017.11.001.
12. Guo, Y.; Gasparrini, A.; Armstrong, B.G.; Tawatsupa, B.; Tobias, A.; Lavigne, E.; Coelho, M.d.S.Z.S.; Pan, X.; Kim, H.; Hashizume, M.; et al. Heat Wave and Mortality: A Multicountry, Multicommunity Study. *Environ. Health Perspect.* **2017**, *125*, 87006, doi:10.1289/EHP1026.
13. Lee, W.; Choi, M.; Bell, M.L.; Kang, C.; Jang, J.; Song, I.; Kim, Y.-O.; Ebi, K.; Kim, H. Effects of urbanization on vulnerability to heat-related mortality in urban and rural areas in South Korea: a nationwide district-level time-series study. *Int. J. Epidemiol.* **2022**, *51*, 111–121, doi:10.1093/ije/dyab148.
14. Stewart, I.D.; Oke, T.R. Local Climate Zones for Urban Temperature Studies. *Bulletin of the American Meteorological Society* **2012**, *93*, 1879–1900, doi:10.1175/BAMS-D-11-00019.1.
15. Zhou, Y.; Zhang, G.; Jiang, L.; Chen, X.; Xie, T.; Wei, Y.; Xu, L.; Pan, Z.; An, P.; Lun, F. Mapping local climate zones and their associated heat risk issues in Beijing: Based on open data. *Sustainable Cities and Society* **2021**, *74*, 103174, doi:10.1016/j.scs.2021.103174.
16. Hamin, E.M.; Gurran, N. Urban form and climate change: Balancing adaptation and mitigation in the U.S. and Australia. *Habitat International* **2009**, *33*, 238–245, doi:10.1016/j.habitatint.2008.10.005.
17. Jalalzadeh Fard, B.; Mahmood, R.; Hayes, M.; Rowe, C.; Abadi, A.M.; Shulski, M.; Medcalf, S.; Lookadoo, R.; Bell, J.E. Mapping Heat Vulnerability Index Based on Different Urbanization Levels in Nebraska, USA. *Geohealth* **2021**, *5*, e2021GH000478, doi:10.1029/2021GH000478.
18. Wang, Y.; Li, X.; Li, J.; Huang, Z.; Xiao, R. Impact of Rapid Urbanization on Vulnerability of Land System from Complex Networks View: A Methodological Approach. *Complexity* **2018**, *2018*, 1–18, doi:10.1155/2018/8561675.
19. 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*, 2032, doi:10.3390/su11072032.
20. Gencer, E.A. *The interplay between urban development, vulnerability, and risk management*: *A case study of the Istanbul metropolitan area;* Springer: Heidelberg, New York, Dordrecht, London, 2013, ISBN 978-3-642-29470-9.
21. Birkmann, J.; Cardona, O.D.; Carreño, M.L.; Barbat, A.H.; Pelling, M.; Schneiderbauer, S.; Kienberger, S.; Keiler, M.; Alexander, D.; Zeil, P.; et al. Framing vulnerability, risk and societal responses: the MOVE framework. *Nat Hazards* **2013**, *67*, 193–211, doi:10.1007/s11069-013-0558-5.
22. Birkmann, J.; Welle, T. Assessing the risk of loss and damage: exposure, vulnerability and risk to climate-related hazards for different country classifications. *IJGW* **2015**, *8*, 191, doi:10.1504/IJGW.2015.071963.
23. Birkmann, J.; Jamshed, A.; McMillan, J.M.; Feldmeyer, D.; Totin, E.; Solecki, W.; Ibrahim, Z.Z.; Roberts, D.; Kerr, R.B.; Poertner, H.-O.; et al. Understanding human vulnerability to climate change: A global perspective on index validation for adaptation planning. *Sci. Total Environ.* **2022**, *803*, 150065, doi:10.1016/j.scitotenv.2021.150065.
24. Diaz-Sarachaga, J.M.; Jato-Espino, D. Analysis of vulnerability assessment frameworks and methodologies in urban areas. *Nat Hazards* **2020**, *100*, 437–457, doi:10.1007/s11069-019-03805-y.
25. Government of Pakistan. Pakistan Demographic Survey: Pakistan Bureau of Statistics, Ministry of Planning, Development and Special Initiatives. Available online: https://www.pbs.gov.pk/publication/report-key-findings-pakistan-demographic-survey-2020 (accessed on November 2022).
26. The Urban Unit. *Punjab Cities Growth Atlas 1995-2015*, 2018.
27. Aslam, A.; Rana, I.A.; Bhatti, S.S. Local climate zones and its potential for building urban resilience: a case study of Lahore, Pakistan. *IJDRBE* **2022**, *13*, 248–265, doi:10.1108/IJDRBE-08-2021-0116.
28. Rana, I.A.; Bhatti, S.S. Lahore, Pakistan – Urbanization challenges and opportunities. *Cities* **2018**, *72*, 348–355, doi:10.1016/j.cities.2017.09.014.
29. CNN. Climate change is making record heatwaves in India and Pakistan 100 times more likely [Online], May 30, 2022. Available online: https://edition.cnn.com/2022/05/18/asia/climate-india-pakistan-heatwave-intl/index.html (accessed on 30 May 2022).
30. Iqbal, N.; Ravan, M.; Jamshed, A.; Birkmann, J.; Somarakis, G.; Mitraka, Z.; Chrysoulakis, N. Linkages between Typologies of Existing Urban Development Patterns and Human Vulnerability to Heat Stress in Lahore. *Sustainability* **2022**, *14*, 10561, doi:10.3390/su141710561.