SURFACE URBAN HEAT ISLANDS AND RELATED HEALTH RISK IN THE PHILIPPINES: A GEOSPATIAL ASSESSMENT USING MODIS DATA

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ABSTRACT:

The study assessed the heat-health risk of the Philippines during 2020 using the MODIS derived Urban Heat Island (UHI) and gridded population data. The study found out that the urban areas experienced more intense heat than the rural areas. It also revealed that the UHI is more intense during March, April and Month or hot dry season. People living in Metro Manila are more exposed and vulnerable to the heat risk. Poverty is one reason that puts people exposed and vulnerable to the heat risk. The output of this study can aid decision-makers especially the urban planners.

1. INTRODUCTION

Human-induced climate change has caused widespread adverse impacts to nature and people. Notably, the higher chance of droughts and wildfires, the increased tropical cyclone intensity and damages, coral bleaching, extreme heat and frequent heat waves (Intergovernmental Panel on Climate Change, 2022).

Numerous studies have linked the extreme heat as a threat to human health (Shildell et al., 2020; Ebi et al., 2021). Adverse health effects are dizziness, headache, heat exhaustion, and in some instances, worsening chronic conditions, or death (Bai et al., 2014; Ebi et al, 2021; Lo et al., 2022). Some pointed out that people living in the urban areas are more prone to this hazard because these areas experienced more intense temperature than their surroundings (Ramamurthy & Bou-Zeid, 2016; Zhao et al., 2018). The temperature difference between urban and rural areas is a worldwide phenomenon called Urban Heat Islands (UHI). The cause of this phenomenon is the removal or conversion of vegetation to impervious surfaces such as housings, roads and commercial buildings in response to urbanization (Cruz et al., 2019).

There are growing efforts that focus on evaluating the current impacts and future risk of extreme heat to human health (Knowlton et al., 2008). But there is still no standard approach since the data availability varies in different countries. Recent study (Tuholske et al., 2020) assessed the global urban population exposure to extreme heat using Heat Index, Wet-bulb globe temperature, and population data. In the case of the Philippines, heat health risk assessment of different cities used remotely sensed data, socio-ecological indicators (Estoque et al., 2020). To know the minimum temperature threshold, the latter study used Land Surface Temperature and the mortality data. The mortality data that were used were not specific to deaths brought on by the heat, which might not be able to get the best estimation of people that are at risk to the extreme heat.

This study adopted the methodology used by Tomlinson et al., 2011 that used population density and remotely sensed data that can be downloaded over the internet. It is concentrated on the spatial identification of those at risk and does not specify a specific temperature threshold which makes it more reproducible to other locations.

2. MATERIALS AND METHODS

2.1 Study Area

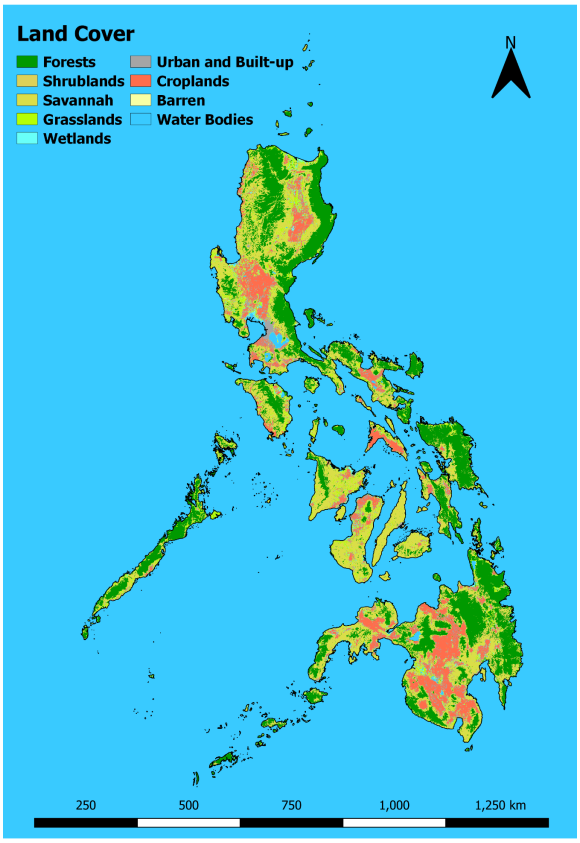

Figure 1. Land Cover Map of the Philippines.

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The Philippines is geographically located along the Pacific Ring of Fire and typhoon belt, which makes the country highly exposed to various natural hazards, including typhoons, flooding, landslides, earthquakes, and volcanic eruptions (Office of Civil Defense, 2018). The country has a humid tropical climate characterized by high temperatures and heavy rainfall which will become increasingly unpredictable by 2050 due to climate change (Giles et al., 2019).

Figure 2 shows the monthly mean temperature and precipitation during 2020. It shows that May has the highest recorded temperature throughout the year, while the highest monthly accumulated rainfall is during the month of December.

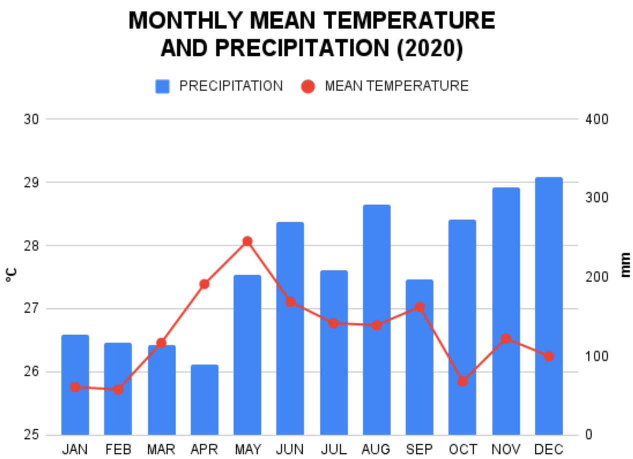

Figure 2. Monthly mean temperature and precipitation in the Philippines in 2020. May was the warmest month and the highest monthly rainfall occurred in December.

2.2 Data Used

The Moderate Resolution Imaging Spectroradiometer (MODIS) (https://modis.gsfc.nasa.gov/) satellite LST data is used to measure the magnitude of UHI in the Philippines. The UHI output is used as a hazard layer for this study. In order to have insight of the climate in the year 2020, the study also gathered the observed temperature and rainfall data. The observed historical data is produced by the Climatic Research Unit (https://www.uea.ac.uk/groups-and-centres/climatic-research-unit) of University of East Anglia. The 2020 population density as input information for the exposure layer, and 2020 elderly (60-85 years old) population for the vulnerability layer. The datasets are combined to assess the exposed and vulnerable population to the extreme temperature caused by UHI phenomenon.

2.3 Data Processing

The study used the IPCC's conceptual framework on risk, which is an interaction between climate-related hazards with exposure and vulnerability (IPCC, 2022). The term "hazard" alludes to potential unfavorable natural or human-caused occurrences that could affect weak and exposed components, in this case the elevated UHI intensity. The term "exposure" describes the components of a space where hazards might occur; in this case, the exposure is the human population. The term "vulnerability" refers to the exposed groups that might experience adverse harm, in this case the elderly population.

2.3.1 Hazard: Urban Heat Island

The study used the MODIS LST daily data to produce monthly and annual LST data for the year 2020. Urban thermal field variance index (UTFVI) was used to quantitatively measure the UHI vulnerability of the area (Alcantara et al., 2019). UTFVI can be calculated using the equation:

$$UTFVI = \frac{T_s - T_{mean}}{T_s} \qquad (1)$$

Where, Ts is the LST, Tm is the mean LST of the area. Instead of getting the mean LST per municipalities or regions, the researcher used zonal statistics to produce a mean LST for 50-km radius neighborhoods. The 50-km radius neighborhood was chosen for the study because it accurately detects the city or municipality with UHIs than the smaller scales, and the 50-km scale offers a better representation of the surrounding areas.

The monthly and annual mean LST and LST 50km radius neighborhood are used as input information to compute the monthly and annual UHI of the Philippines. The study used the normalized monthly and annual UHI outputs as proxy to heat hazard.

Based on the LST and UHI outputs, the researchers created a 1-km fishnet using the ArcGIS Pro software. It will be applied to align the exposure and vulnerability layers with the hazard layer.

2.3.2 Exposure: Population Density

The 2020 unconstrained population density (UN adjusted) data of WorldPop (https://hub.worldpop.org/) was used as an input information for the exposure layer of this study. The population density data were constructed by dividing the population count raster by the land area raster for a specified target year. Each 1km grid-cell of the data represents a population estimate that has been adjusted to correspond with the United Nations' official population estimates (WorldPop, 2018).

In order to have the same pixels, the fishnet that was created using the hazard layer is used along with the 2020 population density data. The output will be used to represent the population exposed to the hazard, which is urban heat islands.

2.3.3 Vulnerability: Elderly Population

The WorldPop creates unique population datasets for both males and females based on the various age ranges. The gridded data are estimated using subnational data on population age and structures (Pezzulo, C. et al. 2017). The datasets can be accessed and downloaded via the WorldPop website.

Heat-health studies stated that older people are more vulnerable to extreme temperatures due to their existing illness and low tolerance to handle it (Ebi et al., 2021; Flynn et al., 2007; Knowlton et al, 2007; Worfolk, 2000). The study concentrated on 2020 population datasets of people aged 60 to 80. A raster calculator was used to merge the target population datasets, and zonal statistics and fishnet were used to resample the data from 100m to 1km resolution. The output will be used to present the distribution of the elderly/vulnerable population.

2.3.4 Heat Health Risk

To represent each variable on the same scale and make it simple to combine layers of various types, a normalizing technique has been used. The equation used for the heat health risk assessment is based on IPCC's definition of risk (Philippine Atmospheric, Geophysical and Astronomical Services Administration, 2021):

$$\text{RISK} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability} \tag{2}$$

All outputs generated in this study are analyzed to assess the population that are exposed and vulnerable to the urban heat hazard.

3. RESULTS AND DISCUSSION

3.1. UHI as Heat Hazard

Based on the annual UHI spatio-temporal analysis (Figure 3), it can be observed that the UHI is not equally distributed throughout the country. With the aid of land cover map (Figure 1) the study found out that the high values are observed in the urban and savannah areas, specifically in Metro Manila, parts of Cavite and Laguna, Cebu City, Cagayan de Oro, General Santos and other highly urbanized areas. On the other hand, low UHI values are observed in rural and mountainous areas.

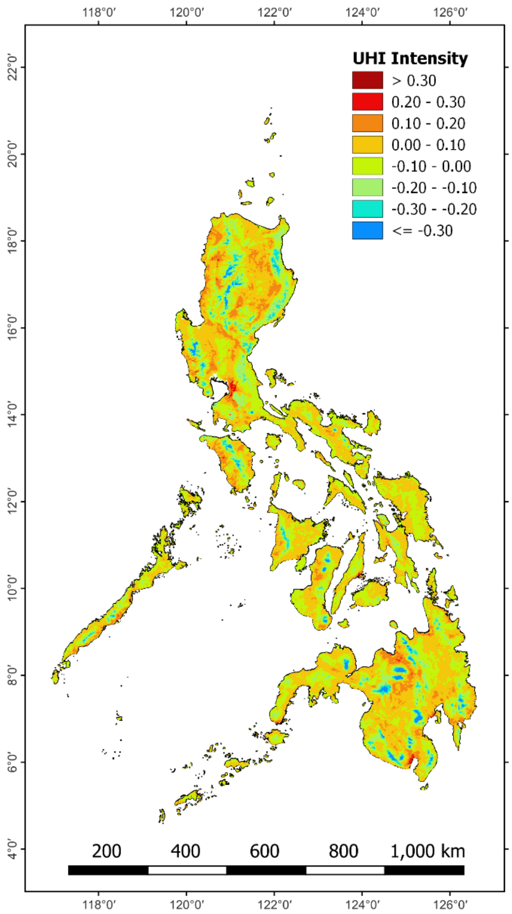

Figure 3. The UTFVI-based UHI output revealed that almost half of the total area of the country is experiencing extreme heat. The UHI effect is more prominent in highly urbanized areas such as Metro Manila, Cebu City, and Cagayan de Oro.

The study also compared the UHI w/ 50-km circular neighborhood output and the UHI output that used the mean LST of the country (Figure 4). It can be seen that the values of UHI with a 50-km neighborhood are much lower compared to the second UHI.

The UHI layer was compared with LST mean output (Figure 5), the study found out that the UHI increases at the 50-km circular neighborhood scale. It also appears that UHI hotspots in the eastern part of the country are not considered as hotspots in LST layer.

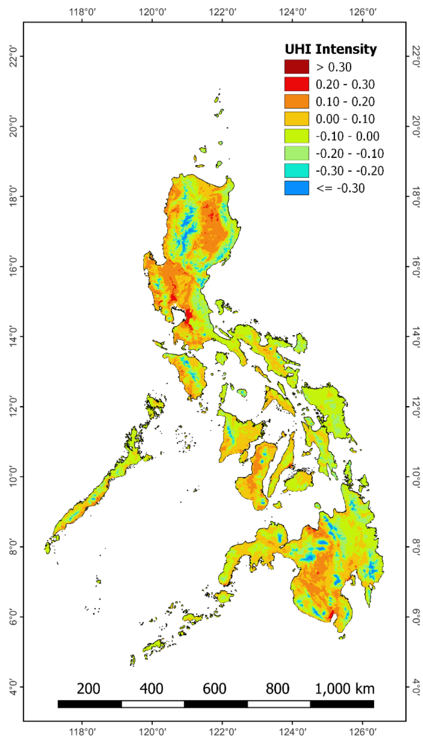

Figure 4. UHI output using the mean LST of the country

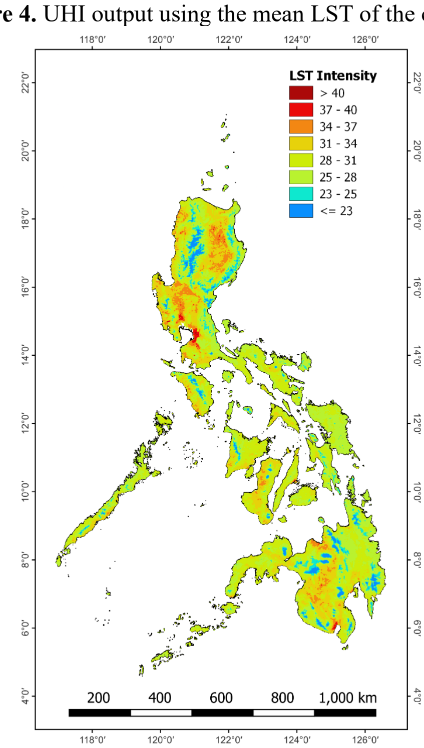

Figure 5. Spatial distribution of mean LST in the country in 2020.

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The monthly UHI maps (Figure 6) revealed that the country experienced more extreme UHI during March, April and May (MAM), and a plausible explanation behind this are the behaviors of temperature and precipitation in those months (Figure 2). The MAM are the hot dry season months in the Philippines, during this season the country receives more direct sunlight and less rainfall that causes the temperature to rise. The distribution pattern of hot spots and cold spots are the same as the annual UHI.

In general, the heat hazard distribution pattern is evidence that there is a great temperature difference between the urban and rural areas.

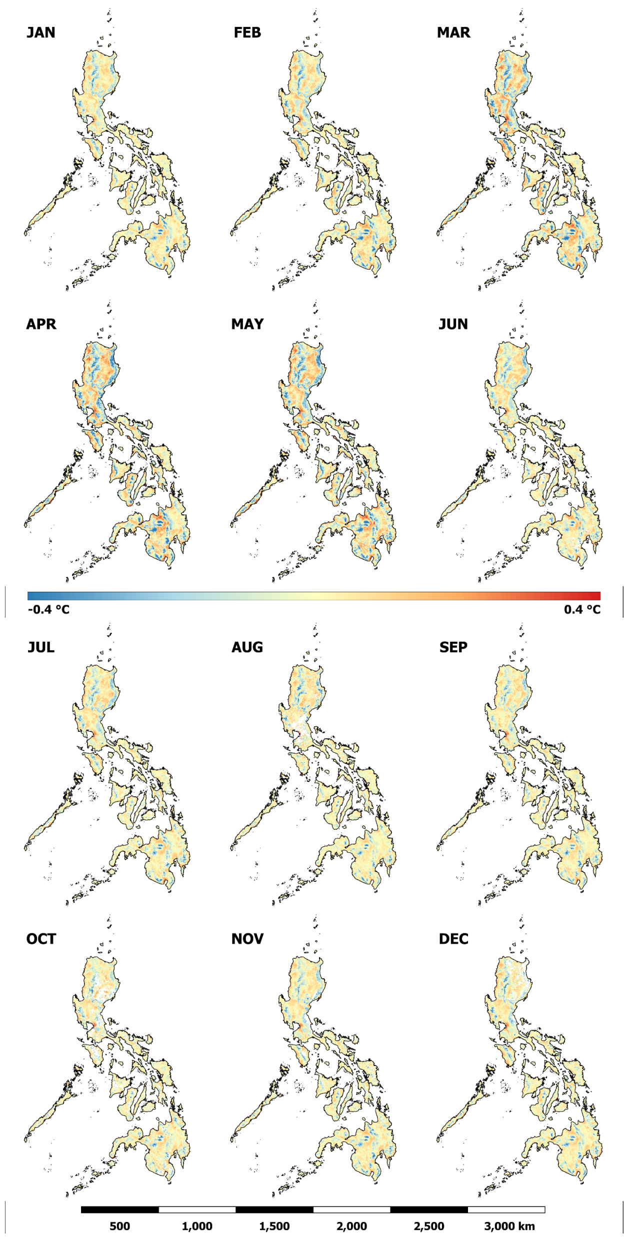

Figure 6. The spatio-temporal distribution of UHI in the Philippines during 2020. It shows that the UHI is intense during the hot dry season (March - April - May). It also shows that the UHI intensity is not equally distributed throughout the country.

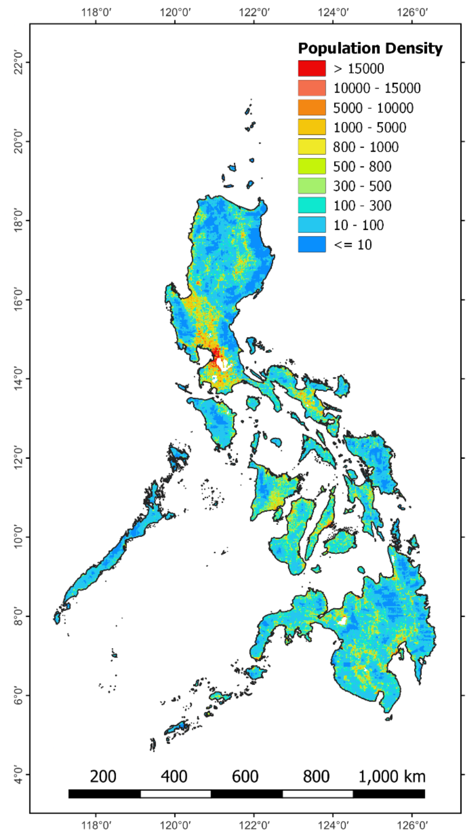

Figure 7. Spatial distribution of people in2020 based on the population density data from WorldPop. The population in metropolitan areas is denser than in rural areas.

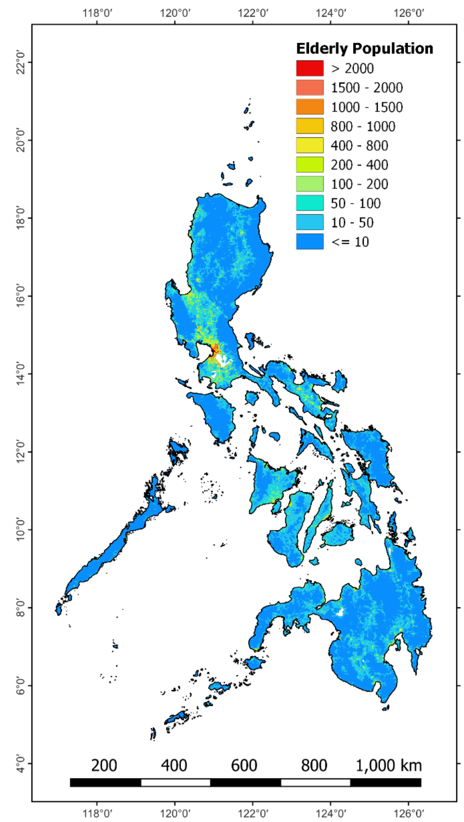

Figure 8. The dense population of elderly are found in urban areas, specifically in Metro Manila

3.2 Exposed Population

Figure 7 revealed that high UHI values during 2020 were seen in Metro Manila, which has a population density of more than 15,000 people per square kilometer. Previous studies mentioned that one-third of Metro Manila's population lives in informal settlements, where insufficient housing and lack of infrastructure are frequently cited as the main root of problems (Morin, et al., 2016). This suggests that in addition to urbanization, poverty is a factor in the influx of people into cities.

Based on the exposure layer output, the most densely populated areas are also the areas that have high UHI values which is the same as the previous studies (Coutts et al., 2007). This implies that a large number of people are exposed to the elevated temperatures induced by UHI.

3.3. Vulnerable Population

Figure 8 revealed that most of the Filipino elders are living in urban areas. This is in contrast with the case of the United Kingdom, where most of the elderly individuals are found in the countryside or rural areas (Tomlinson et al, 2011). Since there are lot of job opportunities in the urban areas compared to rural areas, the elderly Filipinos might stayin in urban areas to do labor despite being frail and old, because (1) they still support the needs of their family, or (2) they need to support themselves because they do not have a pension or sufficient retirement finances (Carandang et al., 2019; Ofreneo, 2013).

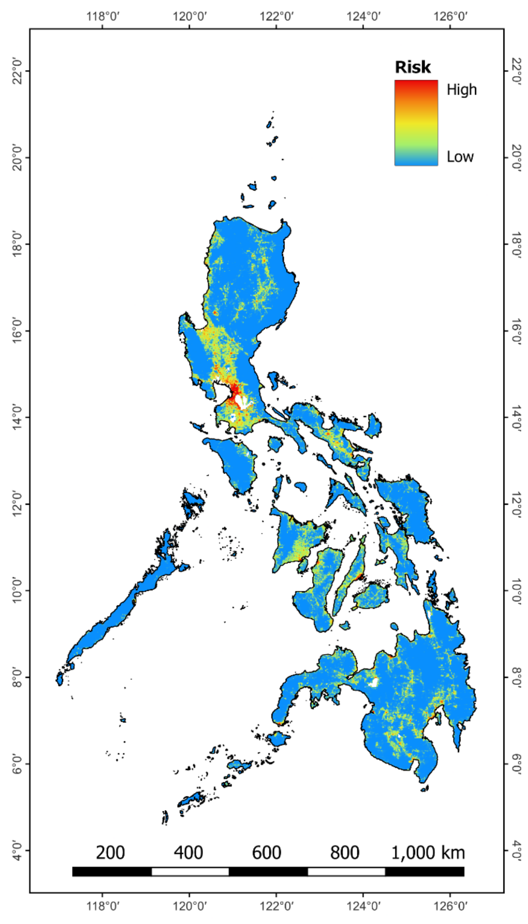

Figure 9. The urban heat risk map revealed that the urban populated areas are more likely to experience the impact of extreme heat.

3.4 Heat Health Risk

Figure 9 shows the majority of identified areas that experienced high heat health risk values are found in the highly urbanized areas of the Philippines. The heat health risk is most prominent in Metro Manila and this can be explained by the distribution of heat hazard and exposed human population.

The heat health risk map also showed that the likelihood of having a high UHI increased with population density (Manoli et al., 2019). Besides the elderly people, the less fortunate people can be classified too as vulnerable since they tend to live in informal settlements in urban areas which are likely to be a crowded place and don't have good ventilation that makes the place hotter.

The study suggests that proper planning for the relocation of people to rural areas might help to mitigate the UHI effect. Proper planning includes the: creation of job opportunities with competitive wages in rural areas, an easy access to the basic necessities, and environmental planning.

4. CONCLUSION

The highly urbanized areas in the Philippines are experiencing warmer temperatures than rural areas. The temperature difference or Urban Heat Island (UHI) is prominent during March, April and Month or hot dry season. The UHI effect is especially severe in Metro Manila, where millions of Filipinos live. This implies that a large number of individuals are exposed to the elevated temperatures induced by UHI. Among these large numbers are older people, which is weak and frail that makes them more susceptible to experienced health related problems caused by the extreme heat.

5. RECOMMENDATION AND FUTURE WORK

The study is limited to the existing and available data. A reliable and complete dataset of heat-related mortalities, high spatial resolution of every household is necessary to have a more comprehensive analysis. The authors of this study have a plan to examine the spatio-temporal trend and variability of UHIs as well as the evolving risks of increased temperature to the human and environment.

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