International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 10 No. 4, 2025
https://www.theaspd.com/ijes.php

Urban Heat Island Effect In The Megacities Of The Philippines

Kristina M. San Jose[1,2], Analiza H. Ibay[1,2], and Jervie M. Oliveros[1,2]

1. Physics Department, Technological University of the Philippines, 2. WEather and ClimAte Resilience (WE CARE) Research Group.
Corresponding author: jervie_oliveros@tup.edu.ph

Abstract: The three megacities namely Cebu City, Davao City and Manila City are considered as highly urbanized cities in the Philippines. The migration of the rural dwellers to these cities are the cause of fast urbanization. To meet the demand for housing, better roads and economic growth, the use of land was shifted from natural ecosystems (such as vegetation, parks, forest) into artificial environments (such as high-rise commercial and residential buildings). These changes in both population densities and land uses greatly alter the weather and climate of these areas.

Studies show urbanization greatly affects local weather, particularly temperature and rainfall patterns of the urban and nearby rural areas. The development of Urban Heat Island (UHI) effect is also documented as this brings discomfort and health related issues among urban dwellers. Using the Diurnal Temperature Range (DTR) values of the selected cities, the researchers investigated the development of UHI. The meteorological parameters of the three cities were generated by the Weather Research and Forecasting Model (WRF).

Results showed that there are more hot days during the hot and wet period than hot and dry periods as revealed by the values of $T_{max.}$ Manila was warmer than areas under study during the hot and dry period. Early morning (T_{min} , 5-AM) temperature of Manila is hotter with mean value of 27.3°C. In general, among the three cities Davao had the coolest morning temperature by approximately 1°C – 3°C. The differences of DTR are ranging from 0.15°C to 1°C. The predominance of UHI is observed during the dry and wet period and weak during the cool and dry period. Overall, UHI development occurred for the entire period of study.

Keywords: Urban Heat Island, Weather Research and Forecasting, Diurnal Temperature Range.

1. Introduction

The cities, as compared to rural areas, are densely populated areas that consume a huge amount of energy and produce more anthropogenic heat. The common materials making up cities are characterized by high heat capacities such as roads, the walls and roofs of the buildings which absorb more solar radiation relative to the natural landscape of rural areas. This increase in radiation emitted from the ground and building surfaces leads to turbulent convection, which may modify the pattern of the temperature.

The poor ability of the city to push energy upward and improper ventilation in urban areas resulted in increased temperature. Open areas have been replaced by infrastructure due to high demand for development in a lot of underdeveloped nations (Rushayati, 2016). Relative to developed nations and regions, there is limited understanding on tropical urban climate and on how urbanization and climate increased the Urban Heat Island effect (Sari, 2021).

The UHI is a phenomenon where a large temperature differential can be seen within a city, between a city and its suburbs, and/or between a city and its surrounding rural areas. Fujibe (2011) classified the UHI effects into two broad categories namely: people and micro-climates. Human's well-being is affected by global warming and urban meteorology.

According to Oke (1982), urbanization is a man-made modification that causes surface material changes as a result of soil sealing, plant suppression, and altered albedo. The UHI development and the local energy balance are both impacted by these changes. Ren et al., (2008) estimated a positive trend in urban warming at 0.11 °C/decade for the period 1960 to 2000 in China and 0.06 C/year in the United States. The trends in temperature revealed that minimum and maximum temperature increased in almost all parts of the globe (Vose et al., 2005). Tropical cities are perpetually warm and sunny, and heat islands can exacerbate the discomfort of crowded cities. In tropical areas during the rainy season, the intensity peaked (medium magnitude) throughout the day. Unlike tropical regions, which are most severe at night and during months of higher temperatures and little precipitation (Loibl, 2021 and Amorim, 2017).

The Metropolitan areas of Manila (1,900,000) Davao (1,828,000) and Cebu (973,000) belong to the top 10 most populated cities in the Philippines (2020 Projected Midyear Population, PSA). Due to their location, these cities become the economic development, educational centers, relay hubs and tourist areas. These affect the demands of housing and infrastructure. To meet the demands, initial vegetation areas are converted into industrial facilities, high-rise buildings and asphalted roads. Due to these changes, researchers investigated the occurrence of UHI in the three of the metropolitan areas in the Philippines using the NCEP FNL Reanalysis data for the months of January, April, July and October of 2016. The data will be generated to these cities using Weather Research and Forecasting. The result will serve as a future reference of urban planners and architects.

2. Method

a. Domain

The cities of Manila, Cebu and Davao are included in the top ten most populated urban areas in the Philippines. They are geopolitically representing the primary island group of the Philippines namely: of the Luzon (for Manila), the Visayas (Cebu) and the Mindanao (Davao), the three major island groups of the Philippines.

The increasing population of these cities resulted in modification of its land use. Figure 1 illustrates the land cover of the selected cities. The brown land covers on the maps represent urban built-up areas, in which initially vegetative or grassland areas but now transformed into asphalted roads, pavements and buildings. The selected areas under study are the megacities of the Luzon (for Manila), the Visayas (Cebu) and the Mindanao (Davao), the three major island groups of the Philippines.

A B C

Legend: urban built-up (brown), vegetative, grassland (green) clouds (white), and water (blue)

Figure 1. Geographic locations of the cities of: Manila (A), Cebu (B) and Davao (C). Retrieved from NASA Landsat Image

More detailed land use classification was illustrated in Figure 2. Based on the Atlas of Urban Expansion (atlasofurbanexpansion.org), the urban extent density in Metro Manila had increased by 0.8 % since 2000, from 159 persons per hectare to 176 in 2014. In Metro Cebu, it had increased by 0.2% (same period as Metro Manila), from 123 to 127 people per hectare. Davao, the second most populous area in the Philippines, only 7 % of its land area is urbanized (IM4Davao 2045).

Figure 2 also showcases the urban sprawl as the cities extend into their neighboring rural regions. This phenomenon is driven by a substantial need for housing and commercial areas within the limited confines of the existing urban landscape. As these urban spaces prove inadequate to meet the growing demand, approaches like verticalization and land reclamation have been explored as solutions to address this spatial constraint. Presently, specific segments of the bays situated within the studied metropolitan zones are undergoing transformation into engineered urban centers, reflecting a concerted effort to create artificial urban spaces.

A B C

Legend (A and B): urban built-up (purple), yellow (urbanized free space), and green (rural areas). (C): Green (agricultural), yellow (residential), red (commercial), and purple (built-up)

Figure 2. Detailed Land Use of the three Metropolitan Areas of the Philippines

b. **Data Acquisition**

The Weather Research and Forecasting (WRF) model consists of three distinct executable files: geogrid.exe, ungrib.exe, and metgrid.exe. The geogrid.exe component initializes the geography, topography, and land characterization, as described by Skamorock et al. (2005). Subsequently, the ungrib.exe utility converts the downloaded NCEP FNL data, which has a resolution of 1° x 1° in grib2 format, making it compatible and interpretable by the model. Lastly, the metgrid.exe module interpolates the meteorological data onto the designated spatial domain.

To initialize the boundary conditions, one week spin-up time was preselected in the study every time of weather simulation. By doing this, the model can modify its internal state variables, such as temperature, pressure, humidity, and wind fields, to achieve an equilibrium state that accurately captures the atmospheric conditions at the beginning of the simulation. The model's transition from the arbitrary initial circumstances to those that are typical of the environment at the start of the simulation is aided by the spin-up time (Lavin-Gullon et. al., 2023 and Jerez et. al., 2020).

To enhance computational efficiency and expedite simulation time, the model configuration was adjusted to generate meteorological data at three-hour intervals. This optimization strategy ensures the timely generation of essential meteorological outputs while minimizing the computational workload.

The Philippines features a tropical climate, characterized by generally consistent temperatures with slight fluctuations across different periods. Notably, the maximum temperature (T_{max}) tends to be observed between 2:00 PM and 5:00 PM each day. Conversely, the minimum temperature (T_{min}) typically occurs between 4:00 AM and 7:00 AM.

The WRF Model was configured to record temperature data at three-hour intervals. The temperature pattern, the highest and lowest temperatures are frequently generated at 2:00 PM and 5:00 AM, respectively. So, the researchers have chosen to designate 2:00 PM as T_{max} and 5:00 AM as T_{min} in their analysis.

The selected months of January, April, July, and October were chosen to represent 4 periods of 2016. The classifications shown in Table 1 are based on PASAGA climate classification (weather bureau in the Philippines).

Table 1. Climate and Weather Classifications

December	Cool and dry months of the year which was characterized by Northeast monsoon (Amihan)
*January	
February	
March	

*April	Easterlies or the transition period with hot and dry months.
May	
June	Southwest monsoon (Habagat) brings heavy rains. This is demonstrated by wet and hot air winds.
*July	
August	
September	Another transition period with humid to cool air winds.
*October	
November	

* Months represented the cool and dry (Jan), hot and dry (April), hot and wet (July) and transition (October) periods

The Diurnal Temperature Range (DTR) is the difference between the daily maximum and minimum temperatures, which represent temperature variance within a day. It provides information on weather stability and serves as a key meteorological marker of global climate change. Like the work of Sachindra et al., (2023), this study used the DTR of the selected cities to describe the UHI occurrence.

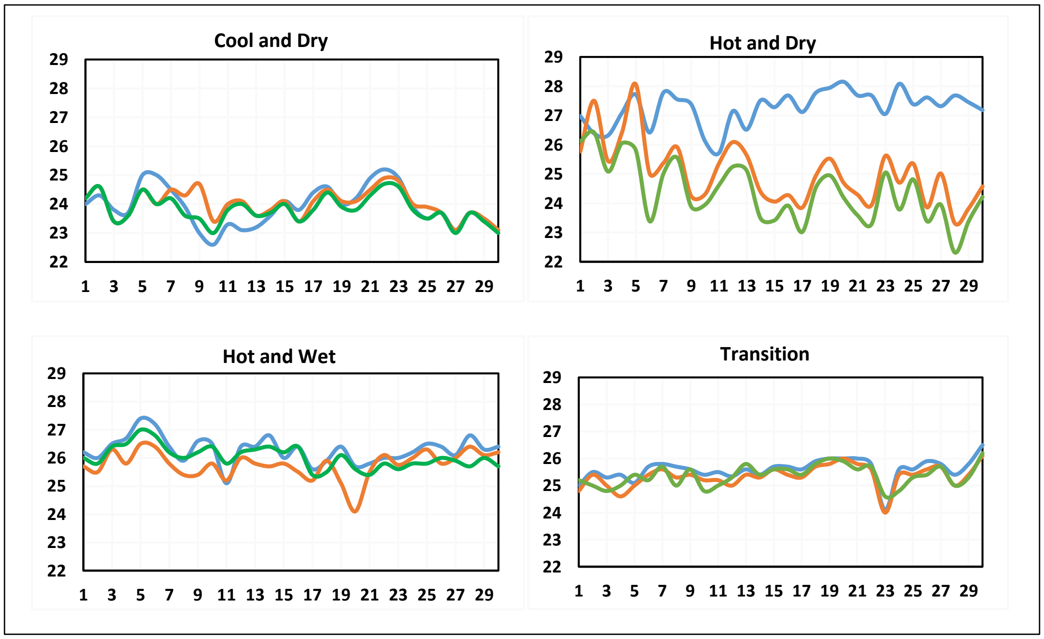
3. **Findings and Discussions**

This work monitored and analyzed the maximum temperature (T_{max}), minimum temperature (T_{min}) and the diurnal temperature range (DTR) of the metropolitan areas particularly Manila, Cebu and Davao. These cities are categorized as urban/build-up areas (USGS).

The variations of generated T_{max} for the four periods of the selected areas are illustrated in Figure 3. As expected, the DJF represented by the temperature obtained by the month of January has the lowest values, ranging from 30.5°C to 32.2°C. On the other hand, the averages of T_{max} in Manila, Cebu and Davao during hot and dry period are 33.60°C, 32.40°C and 30.90°C, respectively. (T_{max} is the temperature at 2PM). Also illustrated in this figure are the T_{max} during hot and wet (July) and transition (October). The ranges of values from these periods are from 31.6 °C up to 34 °C. The mean T_{max} of 32.2 °C to 32.6 °C in July and approximately the same mean of T_{max} (32.5°C) in October is a bit larger than the temperature in April. There are more hot days during July than April. Moreover, there are small variations of simulated T_{max} for January, July and October for the selected areas in the study as compared with T_{max} of April.

Figure 4 illustrates the minimum temperature (T_{min}) values obtained at 5:00 AM, which serve as a representation of the coolest temperatures in the study's selected cities. Across these cities, during the coolest periods, the recorded values span a range from 22.7°C to 25.2°C. Interestingly, the hot and dry period showcases substantial variations among the chosen locations. Specifically, Manila demonstrates a mean T_{min} of 27.3°C, whereas Cebu and Davao exhibit mean T_{min} values of 25°C and 24.4°C, respectively. Notably, the average T_{min} in Davao is notably lower than those in Manila and Davao, differing by approximately 1°C – 3°C. Conversely, minimal disparities are observed in the early morning temperatures during the transition period, where variations range from 0.07°C to 0.15°C.

Figure 3. Temporal and Spatial Variation of Temperature



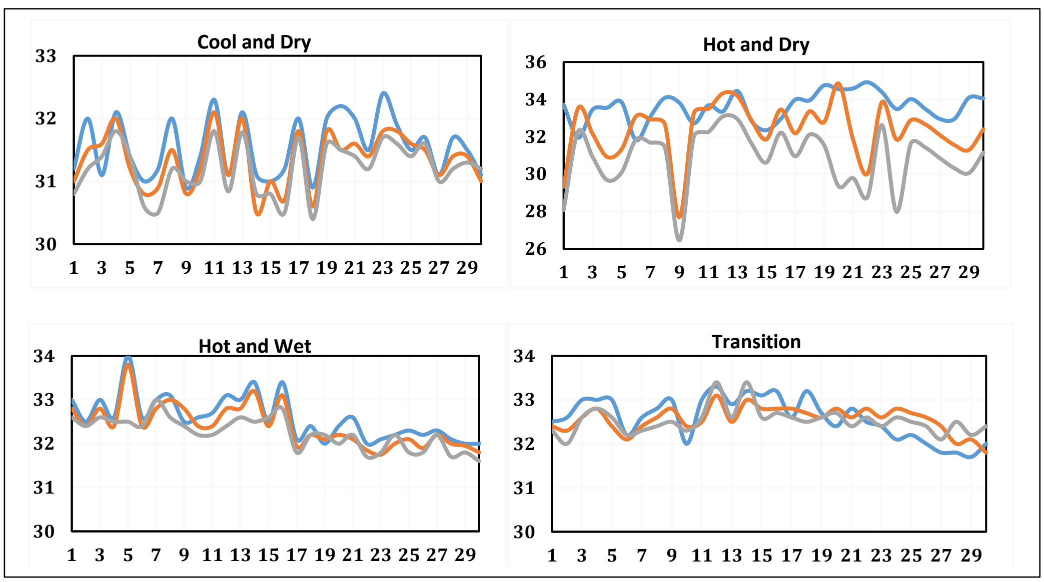


Figure 3-4. Four-Periods T_{max} and T_{min} in **- - Manila**, **- - Cebu - - Davao**

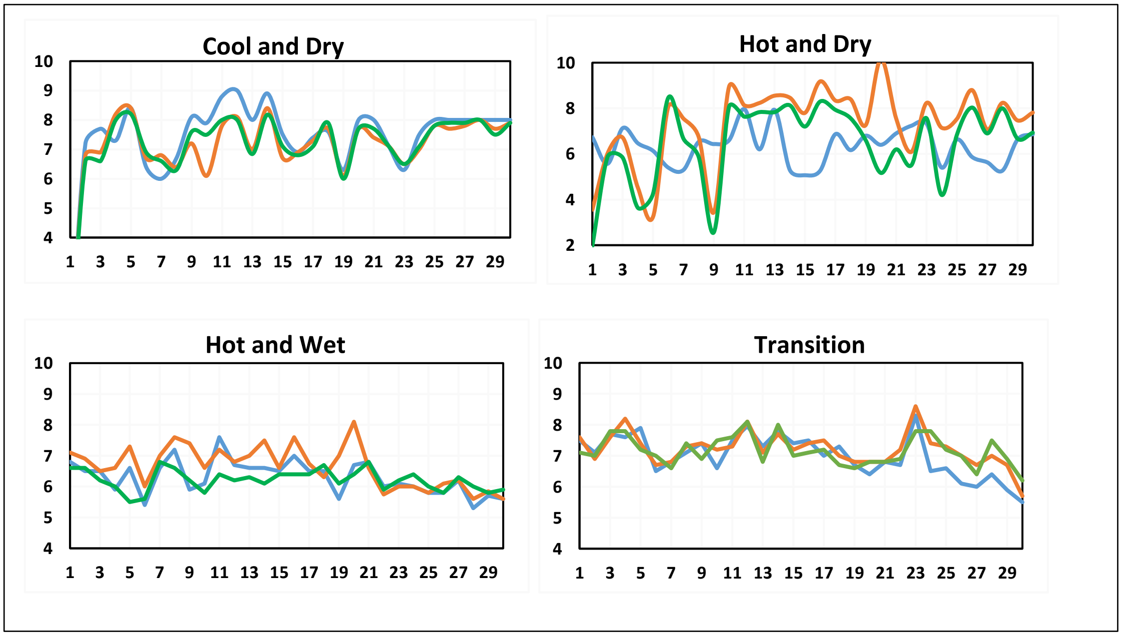
The diurnal temperature range or DTR is represented by the difference between the daily maximum and minimum temperatures within a day. It provides information on whether the weather is steady or not, and it serves as a key meteorological marker of the effects of global climate change (Cheng et. al., 2014).

Figure 5 illustrates the variations in Diurnal Temperature Range (DTR) values across the three cities throughout the periods. The graphical representation portrays how the curves for the cool and dry periods, as well as the transition periods, exhibit overlap. This overlapping trend suggests that the differences in DTR values among Manila, Cebu, and Davao are small with values from 0.05°C to 0.20°C.

The average DTR during hot and dry conditions in Manila is comparably smaller than in Cebu and Davao. In this period, the mean DTR value of Manila is 6.3°C, this is smaller by 0.15 °C in Davao and 1.0 °C in Cebu. During the hot and wet period, Davao measured the lowest mean DTR of 6.21 among the cities. This is around 1.5% and 9% smaller with respect to the values of Manila and Cebu, respectively. Chen et. al., 2021 determined that a DTR threshold of 10° would be a weather condition to express development of UHI.

This result suggested that the intensity of the Urban Heat Island (UHI) for the selected areas depends on the period. The UHI effects are mostly observed during the hot and dry and hot and wet periods of the year. Wu et. al., (2019) and Yusuke et. al., (2018) observed that the summer was when UHI intensity was at its highest and the winter when it was at its lowest. Since urban cooling affects the UHI intensity during the cool and dry period or winter.

Furthermore, the UHI effect in the area may depend on the magnitude of wind speed and direction (Yasuke et al., 2018 and Wu et al., 2010). The proximity of the urban area to the coastlines may also be considered (Wu et. al., 2019).



4. Conclusion

This work successfully utilized the Weather Research and Forecasting (WRF) model to investigate T_{max}, T_{min} and DTR to verify the occurrence, periodic variability of the intensity of UHI of Manila, Cebu and Davao.

Manila obtained the highest T_{max} among the selected metropolitan areas. The T_{max} of hot and dry period obtained a high average among the periods except for Davao. There are more hot days recorded in hot and wet period relative to hot and dry period. This result may be because of the contribution of humidity in the air. The ambient temperature increases by warm and humid air masses which are experienced during wet and transition periods.

For the values of T_{min}, the noticeable high values for Manila as compared to Cebu and Davao particularly on hot and dry periods are approximately 2.3°C to 2.9 °C. This can be associated with the ability of an area to release heat more effectively. In addition, the urban roughness (topography), thermal and optical properties of common structural materials of the cities (such as increased heat capacities and a decrease in surface albedo) has significant effects on temperature.

The UHI intensities can be observed through the differences in the values of T_{max} and T_{min}. Compared to the results of other researchers, UHI of the Megacities such as Manila Cebu and Davao are more predominant during the hot and dry and hot and wet periods with mean values ranging from 6.20 C to 6.50 C. This suggested the periodic variability of UHI intensities.

This UHI occurrences in urban areas may be associated with some factors such as a conversion of grassland and trees that provides shading and cooling effect through evapotranspiration into high heat capacities materials (concreted walls, asphalted roads etc.). In addition, anthropogenic heat is highly considered a variable in climate change.

REFERENCES

1. Amorim, Margarete Cristiane de Costa Trindade, and Vincent Dubreuil. (2017). "Intensity of Urban Heat Islands in Tropical and Temperate Climates" Climate 5, no. 4: 91. https://doi.org/10.3390/cli5040091
2. Chen, G.; He, M.; Li, N.; He, H.; Cai, Y.; Zheng, S. (2021). A Method for Selecting the Typical Days with Full Urban Heat Island Development in Hot and Humid Area, Case Study in Guangzhou, China. Sustainability 13, 320. https://doi.org/ 10.3390/su13010320 Cheng J , Xu Z , Zhu R , et. al., (2014). Impact of diurnal temperature range on human health: a systematic review. Int J.Biometeorol;58:2011–24.doi:10.1007/s00484-014-0797-5 pmid:http://www.ncbi.nlm.nih.gov/pubmed/24535132
3. Cui, Y. Y., & de Foy, B. (2012). Seasonal Variations of the Urban Heat Island at the Surface and the Near-Surface and Reductions due to Urban Vegetation in Mexico City. Journal of Applied Meteorology and Climatology, 51(5), 855–868. doi:10.1175/jamc-d-11-0104.1
4. Final Report Annex A6 IM4Davao GIS Database Development, A6-61-62. Retrieved from https://openjicareport.jica.go.jp/pdf/12308714_03.pdf
5. Jerez, S., Lopez-Romero, J., Turco, M. et al., (2020). On the Spin-up Period in WRF Simulations Over Europe: Trade-offs Between Length and Seasonality. Journal of Advances in Modeling Earth Systems. Vol .12(4). Doi.org/10.1029/2019MS001945
6. Lavin-Gullon, A., Milovac, J., García-Díez, M. et al (2023). Spin-up time and internal variability analysis for overlapping time slices in a regional climate model. Clim Dyn 61, 47–64. https://doi.org/10.1007/s00382-022-06560-2
7. Loibl, Wolfgang, Milena Vuckovic, Ghazal Etminan, Matthias Ratheiser, Simon Tschannett, and Doris Österreicher. (2021). "Effects of Densification on Urban Microclimate—A Case Study for the City of Vienna" Atmosphere 12, no. 4: 511. https://doi.org/10.3390/atmos12040511.
8. Oke, T. R. (1982). The energetic basis of the urban heat island. Quarterly Journal of the Royal Meteorological Society, 108(455), 1–24. doi:10.1002/qj.49710845502
9. Philippine Satistics Authority (PSA) 2020 Projected Midyear Population. Retrieved from https://psa.gov.ph/statistics/census/projected-population
10. Sachindra, D.A., Ullah, S., Zaborski, P. et al. (2023). Temperature and urban heat island effect in Lublin city in Poland under changing climate. Theor Appl Climatol 151, 667–690. https://doi.org/10.1007/s00704-022-04285-0
11. Skamarock, W.C., J.B. Klemp, J. Dudhia, D.O. Gill, D.M. Barker, W. Wang, J.G. Powers, (2005). ARW Version 2, NCAR/TN – 468+STR, NCAR Technical Note 2005 (PDF Document).
12. Ren, G., Y. Zhou, Z. Chu, J. Zhou, A. Zhang, J. Guo, and X. Liu, (2008). "Urbanization effects on observed surface air temperature trends in North China, "J Clim 21:1333-1348.
13. Rushayati, S. B., Prasetyo, L. B., Puspaningsih, N., & Rachmawati, E. (2016). Adaptation Strategy Toward Urban Heat Island at Tropical Urban Area. Procedia Environmental Sciences, 33, 221–229. doi:10.1016/j.proenv.2016.03.073
14. Vose, R. S., Easterling, D. R., & Gleason, B. (2005). Maximum and minimum temperature trends for the globe: An update through 2004. Geophysical Research Letters, 32(23). doi:10.1029/2005gl024379
15. Wu, J.-B., Chow, K.-C., Fung, J. C. H., Lau, A. K. H., & Yao, T. (2010). Urban heat island effects of the Pearl River Delta city clusters—their interactions and seasonal variation. Theoretical and Applied Climatology, 103(3-4), 489–499. doi:10.1007/s00704-010-0323-6
16. Wu, X., Zhang, L., & Zang, S. (2019). Examining seasonal effect of urban heat island in a coastal city. PLOS ONE, 14(6), e0217850. doi:10.1371/journal.pone.0217850
17. Yusuke, N., Yoshinori, S., & Yasushi, W. (2018). Seasonal Variations of the Urban Heat Island in Kumagaya, Japan. Geographical Review of Japan Series B, 91(2), 29–39. doi:10.4157/geogrevjapanb.91.29