IMPACT OF URBANIZATION TO THE RAINFALL PATTERN IN METROPOLITAN MANILA

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An Undergraduate Thesis Submitted to the Faculty of the Department of Engineering Sciences, College of Engineering, Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines in Partial Fulfillment of the Requirements for the Degree of

BACHELOR OF SCIENCE IN METEOROLOGY

MAY 2023

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ABSTRACT

MANUEL, DANVER C., EUGENIO, HANNAH GAZEL D., Department of Engineering Sciences, College of Engineering, Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines, **May 2023, IMPACT OF URBANIZATION TO THE RAINFALL PATTERN IN METROPOLITAN MANILA**

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Urbanization is caused by an increase in the size and density of built-up areas. Environmental degradation has been occurring at a rapid pace as a result of uncontrolled urbanization that causes, numerous problems in an area. Urbanization could have a significant impact on the surface energy budget and further influence the local atmospheric conditions.

This study assessed the impact of urbanization to the rainfall pattern in Metropolitan Manila. The population density data were used to determine the early- and post-urbanization period in Metro Manila, as well as, to determine a nearby rural area which is the basis for assessing the impact of urbanization. On the other hand, 57-year annual rainfall from the Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources (APHRODITE) was used to quantify, and investigate the effect of urbanization on rainfall using spatiotemporal analysis. A statistical method was also used to measure the modulation of urbanization on daily rainfall. The statistical significance of the results was tested using correlation analysis, Mann Kendall trend test, and two-sample independent t-test.

Keywords: *Precipitation, Urbanization, Metro Manila*

LITERATURE CITED

Adhikari, R., & Agrawal, R. K. (2013). *An Introductory Study on Time Series Modeling and Forecasting* (arXiv:1302.6613). arXiv. https://doi.org/10.48550/arXiv.1302.6613

Ahlfeldt, G. M., & Pietrostefani, E. (2019). The economic effects of density: A synthesis. *Journal of Urban Economics*, *111*, 93–107. https://doi.org/10.1016/j.jue.2019.04.006

Angel, S., Parent, J., & Civco, D. L. (2012). The fragmentation of urban landscapes: Global evidence of a key attribute of the spatial structure of cities, 1990–2000. *Environment and Urbanization*, *24*(1), 249–283. https://doi.org/10.1177/0956247811433536

Batty, M. (2008). The Size, Scale, and Shape of Cities. *Science (New York, N.Y.)*, *319*, 769–771. https://doi.org/10.1126/science.1151419

Brenner, N. (2013). Theses on Urbanization. *Public Culture*, *25*(1 (69)), 85–114. https://doi.org/10.1215/08992363-1890477

Burian, S. J., & Shepherd, J. M. (2005). Effect of urbanization on the diurnal rainfall pattern in Houston. *Hydrological Processes*, *19*(5), 1089–1103. https://doi.org/10.1002/hyp.5647

Chen, H., Huang, J. J., Dash, S. S., McBean, E., Wei, Y., & Li, H. (2022). Assessing the impact of urbanization on urban evapotranspiration and its components using a novel four-source energy balance model. *Agricultural and Forest Meteorology*, *316*, 108853. https://doi.org/10.1016/j.agrformet.2022.108853

Chen, S., Li, W.-B., Du, Y.-D., Mao, C.-Y., & Zhang, L. (2015). Urbanization effect on precipitation over the Pearl River Delta based on CMORPH data. *Advances in Climate Change Research*, *6*(1), 16–22. https://doi.org/10.1016/j.accre.2015.08.002

Chen, Z., Cai, J., Gao, B., Xu, B., Dai, S., He, B., & Xie, X. (2017). Detecting the causality influence of individual meteorological factors on local PM2.5 concentration in the Jing-Jin-Ji region. *Scientific Reports*, *7*, 40735. https://doi.org/10.1038/srep40735

Climate of the Philippines. (n.d.). Department of Science and Technology - Philippine Atmospheric, Geophysical and Astronomical Services Administration. Retrieved June 26, 2023, from https://www.pagasa.dost.gov.ph/information/climate-philippines

Cox, W. (2011, April 24). *The Evolving Urban Form: Manila | Newgeography.com*. https://www.newgeography.com/content/002198-the-evolving-urban-form-manila

De Alban, J. D. (2010). Spatial Analysis of Biophysical and Socio-Economic Variables in Support of Decision-Making on Conservation and Development Issues: A Case Study of Mindoro Island, Philippines. https://www.researchgate.net/publication/327221972_Spatial_Analysis_of_Biophysical_and_Socio-Economic_Variables_in_Support_of_Decision-Making_on_Conservation_and_Development_Issues_A_Case_Study_of_Mindoro_Island_Philippines

DTI. (2020). *NCR - Regional Profile | Department of Trade and Industry Philippines*. https://www.dti.gov.ph/regions/ncr/profile/

Duranton, G., & Puga, D. (2004). Chapter 48—Micro-Foundations of Urban Agglomeration Economies. In J. V. Henderson & J.-F. Thisse (Eds.), *Handbook of Regional and Urban Economics* (Vol. 4, pp. 2063–2117). Elsevier. https://doi.org/10.1016/S1574-0080(04)80005-1

Fan, C., Myint, S. W., Kaplan, S., Middel, A., Zheng, B., Rahman, A., Huang, H.-P., Brazel, A., & Blumberg, D. G. (2017). Understanding the Impact of Urbanization on Surface Urban Heat Islands—A Longitudinal Analysis of the Oasis Effect in Subtropical Desert Cities. *Remote Sensing*, *9*(7), Article 7. https://doi.org/10.3390/rs9070672

Hong, J., Agustin, W., Yoon, S., & Park, J.-S. (2022). Changes of extreme precipitation in the Philippines, projected from the CMIP6 multi-model ensemble. Weather and Climate Extremes, 37, 100480. https://doi.org/10.1016/j.wace.2022.100480

Ji, X., Li, Y., Luo, X., He, D., Guo, R., Wang, J., Bai, Y., Yue, C., & Liu, C. (2020). Evaluation of bias correction methods for APHRODITE data to improve hydrologic simulation in a large Himalayan basin. *Atmospheric Research*, *242*, 104964. https://doi.org/10.1016/j.atmosres.2020.104964

Kleniewski, N., & Thomas, A. R. (2011). *Cities, Change, and Conflict: A Political Economy of Urban Life*. Wadsworth Cengage Learning.

Li, Y., Zhang, J., Sailor, D. J., & Ban-Weiss, G. A. (2019). Effects of urbanization on regional meteorology and air quality in Southern California. *Atmospheric Chemistry and Physics*, *19*(7), 4439–4457. https://doi.org/10.5194/acp-19-4439-2019

Lippmann, R. P. (1989). Review of neural networks for speech recognition. *Neural Computation*, *1*, 1–38. https://doi.org/10.1162/neco.1989.1.1.1

Liu, J., & Niyogi, D. (2019). Meta-analysis of urbanization impact on rainfall modification. *Scientific Reports*, *9*(1), Article 1. https://doi.org/10.1038/s41598-019-42494-2

Meliker, J. R., & Sloan, C. D. (2011). Spatio-temporal epidemiology: Principles and opportunities. *Spatial and Spatio-Temporal Epidemiology*, *2*(1), 1–9. https://doi.org/10.1016/j.sste.2010.10.001

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, *108*(455), 1–24. https://doi.org/10.1002/qj.49710845502

P. Vahmani & G. A. Ban-Weiss. (2016, January 7). *Impact of remotely sensed albedo and vegetation fraction on simulation of urban climate in WRF - urban canopy model: A case study of the urban heat island in Los Angeles—Vahmani—2016—Journal of Geophysical Research: Atmospheres—Wiley Online Library*. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015JD023718

Qian, Y., Chakraborty, T. C., Li, J., Li, D., He, C., Sarangi, C., Chen, F., Yang, X., & Leung, L. R. (2022). Urbanization Impact on Regional Climate and Extreme Weather: Current Understanding, Uncertainties, and Future Research Directions. *Advances in Atmospheric Sciences*, *39*(6), 819–860. https://doi.org/10.1007/s00376-021-1371-9

Raflores, L. S., & Regmi, R. K. (2015). *Understanding the Water and Urban Environment of a Megacity: The Case of Metro Manila, Philippines*. 4.

Regmi, R. K. (2017). Urbanization and Related Environmental Issues of Metro Manila. *Journal of Advanced College of Engineering and Management*, *3*, 79–92. https://doi.org/10.3126/jacem.v3i0.18906

Ritchie, H., & Roser, M. (2018). Urbanization. *Our World in Data*. https://ourworldindata.org/urbanization

Seto, K., Fragkias, M., Güneralp, B., & Reilly, M. (2011, August 18). *A Meta-Analysis of Global Urban Land Expansion | PLOS ONE*. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0023777

Shepherd, J. M. (2005, July 1). *A Review of Current Investigations of Urban-Induced Rainfall and Recommendations for the Future in: Earth Interactions Volume 9 Issue 12 (2005)*. https://journals.ametsoc.org/view/journals/eint/9/12/ei156.1.xml?tab_body=fulltext-display

Singh, J., Karmakar, S., PaiMazumder, D., Ghosh, S., & Niyogi, D. (2020). Urbanization alters rainfall extremes over the contiguous United States. *Environmental Research Letters*, *15*(7), 074033. https://doi.org/10.1088/1748-9326/ab8980

Song, X., Mo, Y., Xuan, Y., Wang, Q. J., Wu, W., Zhang, J., & Zou, X. (2021). Impacts of urbanization on precipitation patterns in the greater Beijing–Tianjin–Hebei metropolitan region in northern China. *Environmental Research Letters*, *16*(1), 014042. https://doi.org/10.1088/1748-9326/abd212

Su, T., Sun, S., Wang, S., Xie, D., Li, S., Huang, B., Ma, Q., Qian, Z., Feng, G., & Feng, T. (2022). Spatiotemporal Variation of Actual Evapotranspiration and Its Relationship with Precipitation in Northern China under Global Warming. Remote Sensing, 14(18), 4554. https://doi.org/10.3390/rs14184554

Steensen, B. M., Marelle, L., Hodnebrog, Ø., & Myhre, G. (2022). Future urban heat island influence on precipitation. *Climate Dynamics*, *58*(11), 3393–3403. https://doi.org/10.1007/s00382-021-06105-z

The Impact of Urban Pollution on Rain. (2006, December 11). [Text.Article]. The Earth Observatory; NASA Earth Observatory. https://earthobservatory.nasa.gov/features/UrbanRain/urbanrain3.php

Torrey, B. (2004, April 23). *Urbanization: An Environmental Force to Be Reckoned With*. PRB. https://www.prb.org/resources/urbanization-an-environmental-force-to-be-reckoned-with/

Tysa, S. K., & Ren, G. (2022). Observed decrease in light precipitation in part due to urbanization. *Scientific Reports*, *12*(1), Article 1. https://doi.org/10.1038/s41598-022-07897-8

US EPA, O. (2015, December 29). *Urbanization—Temperature* [Data and Tools]. https://www.epa.gov/caddis-vol2/urbanization-temperature

Uttara, S., Bhuvandas, N., & Aggarwal, V. (2012). Impacts of urbanisation on environment. *IJREAS*, *2*.

Vahmani, P., & Hogue, T. S. (2014). Incorporating an Urban Irrigation Module into the Noah Land Surface Model Coupled with an Urban Canopy Model. *Journal of Hydrometeorology*, *15*(4), 1440–1456. https://doi.org/10.1175/JHM-D-13-0121.1

Wang, H., Liu, Z., Wu, K., Qiu, J., Zhang, Y., Ye, B., & He, M. (2022). Impact of Urbanization on Meteorology and Air Quality in Chengdu, a Basin City of Southwestern China. *Frontiers in Ecology and Evolution*, *10*. https://www.frontiersin.org/articles/10.3389/fevo.2022.845801

Yang, X., Yue, W., Xu, H., Wu, J., & He, Y. (2014). Environmental Consequences of Rapid Urbanization in Zhejiang Province, East China. *International Journal of Environmental Research and Public Health*, *11*(7), 7045–7059. https://doi.org/10.3390/ijerph110707045

Yu, B. (2021). Ecological effects of new-type urbanization in China. *Renewable and Sustainable Energy Reviews*, *135*, 110239. https://doi.org/10.1016/j.rser.2020.110239

Zhao, N., Jiao, Y., Ma, T., Zhao, M., Fan, Z., Yin, X., Liu, Y., & Yue, T.-X. (2019). Estimating the effect of urbanization on extreme climate events in the Beijing-Tianjin-Hebei region, China. *Science of The Total Environment*, *688*. https://doi.org/10.1016/j.scitotenv.2019.06.374