IMPLEMENTASI INTERPOLASI LANCZOS DAN ORDINARY KRIGING DALAM PEMETAAN POLUSI CAHAYA: STUDI KASUS PULAU JAWA DAN KOTA BANDUNG

SKRIPSI

Diajukan untuk memenuhi bagian dari
syarat memperoleh gelar Sarjana Komputer
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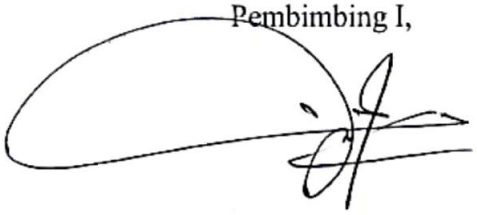
DISETUJUI DAN DISAHKAN OLEH PEMBIMBING:

Pembimbing I,



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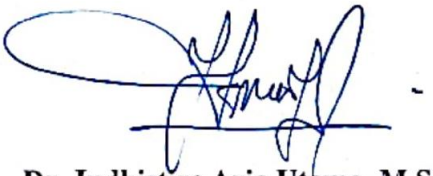
Pembimbing II,



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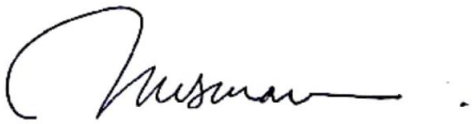

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IMPLEMENTASI INTERPOLASI LANCZOS DAN ORDINARY KRIGING DALAM PEMETAAN POLUSI CAHAYA: STUDI KASUS PULAU JAWA DAN KOTA BANDUNG

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ABSTRAK

Polusi cahaya adalah masalah yang terus berkembang yang mempengaruhi berbagai aspek kehidupan manusia dan lingkungan alam, termasuk pengamatan astronomi. Pemetaan polusi cahaya yang akurat sangat penting untuk pengembangan kebijakan dan tindakan mitigasi yang efektif. Penelitian ini mengevaluasi dua metode interpolasi-interpolasi Lanczos dan Ordinary Kriging-untuk pemetaan polusi cahaya, dengan menggunakan dua set data yang berbeda: Visible Infrared Imaging Radiometer Suite (VIIRS) dan Sky Quality Meter (SQM). Penelitian ini berfokus pada enam ibu kota provinsi di Pulau Jawa: Serang, Jakarta, Bandung, Yogyakarta, Semarang, dan Surabaya. Interpolasi Lanczos diterapkan pada data VIIRS dan secara efektif mengubah resolusi asli 750m x 750m menjadi resolusi 75m x 75m yang lebih halus. Hal ini menghasilkan peta polusi cahaya yang lebih rinci dan dapat diandalkan untuk kota-kota tersebut. Di sisi lain, Ordinary Kriging diterapkan pada data SQM yang dikumpulkan dari 26 titik berbeda di Kota Bandung. Metode ini terbukti dapat diandalkan untuk menghasilkan peta polusi cahaya berkualitas tinggi, terutama di daerah dengan sampel data yang tidak teratur. Penerapan Interpolasi Lanczos dan Ordinary Kriging pada data Kota Bandung menunjukkan adanya perbedaan terutama dalam hal resolusi dan sumber data. Lanczos lebih cocok untuk data berbasis grid seperti VIIRS, sedangkan Kriging lebih cocok untuk data yang diambil secara acak seperti SQM. Terlepas dari perbedaan ini, kedua metode ini menawarkan peta mendalam yang menunjukkan distribusi spasial polusi cahaya di seluruh area yang diteliti. Temuan dari penelitian ini memberikan wawasan yang berharga untuk proyek pemetaan polusi cahaya di masa depan. Dengan memahami karakteristik data dan metode yang digunakan, para peneliti di masa depan dapat membuat keputusan yang lebih tepat dalam memilih metode interpolasi. Hal ini akan menghasilkan peta polusi cahaya yang lebih akurat dan berkontribusi pada pengembangan strategi mitigasi yang lebih efektif.

Kata kunci: *astrofisika, interpolasi, Lanczos resampling, ordinary kriging, polusi cahaya, SQM, VIIRS*

IMPLEMENTATION OF LANCZOS AND KRIGING INTERPOLATION IN LIGHT POLLUTION MAPPING: A CASE STUDY OF JAVA ISLAND AND BANDUNG CITY

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ABSTRACT

Light pollution is a growing concern that affects various aspects of human life and the natural environment, including astronomical observations. Accurate mapping of light pollution is crucial for the development of effective policy and mitigation measures. This study evaluates two interpolation methods—Lanczos interpolation and Ordinary Kriging—for light pollution mapping, using two different datasets: Visible Infrared Imaging Radiometer Suite (VIIRS) and Sky Quality Meter (SQM). The study focuses on six provincial capitals on Java Island: Serang, Jakarta, Bandung, Yogyakarta, Semarang, and Surabaya. Lanczos interpolation was applied to VIIRS data and effectively transformed the original 750m x 750m resolution into a finer 75m x 75m resolution. This resulted in more detailed and reliable light pollution maps for these cities. On the other hand, Ordinary Kriging was applied to SQM data collected from 26 different points in Bandung City. This method proved to be reliable for producing high-quality light pollution maps, particularly in areas with irregular data samples. The implementation of Lanczos Interpolation and Ordinary Kriging on Bandung City data revealed differences mainly in terms of resolution and data source. Lanczos is more suitable for grid-based data like VIIRS, while Kriging is better suited for randomly-sampled data like SQM. Despite these differences, both methods offer in-depth maps that show the spatial distribution of light pollution across the studied areas. The findings of this study provide valuable insights for future light pollution mapping projects. By understanding the characteristics of the data and methods used, future researchers can make more informed decisions in selecting interpolation methods. This will lead to more accurate light pollution maps and contribute to the development of more effective mitigation strategies.

Keywords: astrophysics, interpolation, Lanczos resampling, light pollution, ordinary kriging, SQM, VIIRS

DAFTAR ISI

DAFTAR PUSTAKA

Adams, B. (2019). *Spatial Data Science: Closing the human-spatial computing-environment loop*. https://doi.org/10.48550/ARXIV.1910.06484

Bará, S., Falchi, F., Furgoni, R., & Lima, R. C. (2019). *Fast Fourier-transform calculation of artificial night sky brightness maps*. https://doi.org/10.48550/ARXIV.1907.02891

Bará, S., & Lima, R. C. (2018). Photons without borders: Quantifying light pollution transfer between territories. *International Journal of Sustainable Lighting*, *20*(2), 51–61. https://doi.org/10.26607/ijsl.v20i2.87

Bará, S., Lima, R. C., & Zamorano, J. (2019). Monitoring Long-Term Trends in the Anthropogenic Night Sky Brightness. *Sustainability*, *11*(11), 3070. https://doi.org/10.3390/su11113070

Bará, S., Tapia, C., & Zamorano, J. (2019). Absolute Radiometric Calibration of TESS-W and SQM Night Sky Brightness Sensors. *Sensors*, *19*(6), 1336. https://doi.org/10.3390/s19061336

Baugh, K., Elvidge, C. D., Ghosh, T., & Ziskin, D. (2010). Development of a 2009 Stable Lights Product using DMSP-OLS data. *Proceedings of the Asia-Pacific Advanced Network*, *30*(0), 114. https://doi.org/10.7125/APAN.30.17

Bender, O., Evelpidou, N., Krek, A., & Vassilopoulos, A. (Eds.). (2009). *Geoinformation technologies for geocultural landscapes: European perspectives*. CRC Press, Taylor & Francis Group.

Benn, C. R., & Ellison, S. L. (1998). Brightness of the night sky over La Palma. *New Astronomy Reviews*, *42*(6–8), 503–507. https://doi.org/10.1016/S1387-6473(98)00062-1

Bennie, J., Davies, T. W., Duffy, J. P., Inger, R., & Gaston, K. J. (2014). Contrasting trends in light pollution across Europe based on satellite observed night time lights. *Scientific Reports*, *4*(1), 3789. https://doi.org/10.1038/srep03789

Bergé, J., Price, S., Amara, A., & Rhodes, J. (2011). *On Point Spread Function modelling: Towards optimal interpolation*. https://doi.org/10.48550/ARXIV.1110.2517

Bernstein, G. M., & Gruen, D. (2014). *Resampling images in Fourier domain*. https://doi.org/10.48550/ARXIV.1401.2636

Biswas, S., Chen, F., Chen, Z., Lu, C.-T., & Ramakrishnan, N. (2022). *Memetic algorithms for Spatial Partitioning problems*. https://doi.org/10.48550/ARXIV.2208.02867

Blangiardo, M., Pirani, M., Kanapka, L., Hansell, A., & Fuller, G. (2018). *A hierarchical modelling approach to assess multi pollutant effects in time-series studies*. https://doi.org/10.48550/ARXIV.1808.08142

Bogaert, P. (1996). Comparison of kriging techniques in a space-time context. *Mathematical Geology*, *28*(1), 73–86. https://doi.org/10.1007/BF02273524

Bogard, P. (2013). *The end of night: Searching for natural darkness in an age of artificial light* (First edition). Little, Brown, and Company.

Burger, W., & Burge, M. (2009). *Principles of digital image processing: Core algorithms*. Springer.

Burrouh, P. A. (1986). Principles of geographical information systems for land resource assessment. In *Claredon Press, Oxford, l987, pp. L93*.

Bussberg, N. W., Shields, J., & Huang, C. (2021). *Non-Homogeneity Estimation and Universal Kriging on the Sphere*. https://doi.org/10.48550/ARXIV.2107.02871

Bustamante-Calabria, M., de Miguel, A. S., Martín-Ruiz, S., Ortiz, J.-L., Vílchez, J. M., Pelegrina, A., García, A., Zamorano, J., Bennie, J., & Gaston, K. J. (2020). *Effects of the COVID-19 lockdown on urban light emissions: Ground and satellite comparison*. https://doi.org/10.48550/ARXIV.2011.09252

Chen, T., Greenbaum, A., Musco, C., & Musco, C. (2022). Error Bounds for Lanczos-Based Matrix Function Approximation. *SIAM Journal on Matrix Analysis and Applications*, *43*(2), 787–811. https://doi.org/10.1137/21M1427784

Chepesiuk, R. (2009). Missing the Dark: Health Effects of Light Pollution. *Environmental Health Perspectives*, *117*(1). https://doi.org/10.1289/ehp.117-a20

Cho, Y., Ryu, S.-H., Lee, B. R., Kim, K. H., Lee, E., & Choi, J. (2015). Effects of artificial light at night on human health: A literature review of observational and experimental studies applied to exposure assessment. *Chronobiology International*, *32*(9), 1294–1310. https://doi.org/10.3109/07420528.2015.1073158

Christianson, R. B., Pollyea, R. M., & Gramacy, R. B. (2022). *Traditional kriging versus modern Gaussian processes for large-scale mining data*. https://doi.org/10.48550/ARXIV.2207.10138

Ciancia, V., Latella, D., Loreti, M., & Massink, M. (2016). *Model Checking Spatial Logics for Closure Spaces*. https://doi.org/10.48550/ARXIV.1609.06513

Cinzano, P., Falchi, F., & Elvidge, C. D. (2001). The first World Atlas of the artificial night sky brightness. *Monthly Notices of the Royal Astronomical Society*, *328*(3), 689–707. https://doi.org/10.1046/j.1365-8711.2001.04882.x

Cox, A. N. (Ed.). (2002). *Allen's Astrophysical Quantities*. Springer New York. https://doi.org/10.1007/978-1-4612-1186-0

Crawford, D. L. (2000). Light pollution, an environmental problem for astronomy and for mankind. *Memorie Della Società Astronomica Italiana*, *71*, 11.

Cressie, N. (1990). The origins of kriging. *Mathematical Geology*, *22*(3), 239–252. https://doi.org/10.1007/BF00889887

Cressie, N. A. C. (1993). *Statistics for spatial data*. John Willy and Sons.

de Miguel, A. S. (2022). *Pros and cons of gaussian filters versus step filters for light pollution monitoring*. https://doi.org/10.48550/ARXIV.2209.02100

Deng, X., Zhu, Y., & Newsam, S. (2018). *Spatial Morphing Kernel Regression For Feature Interpolation*. https://doi.org/10.48550/ARXIV.1802.07452

Deutsch, C. V., & Journel, A. G. (1992). *GSLIB: Geostatistical software library and user's guide* [Computer file]. Oxford University Press.

Duchon, C. E. (1979). Lanczos Filtering in One and Two Dimensions. *Journal of Applied Meteorology*, *18*(8), 1016–1022. https://doi.org/10.1175/1520-0450(1979)018<1016:LFIOAT>2.0.CO;2

Duchon, J. (1976). Interpolation des fonctions de deux variables suivant le principe de la flexion des plaques minces. In *Revue française d'automatique, informatique …*. numdam.org. http://www.numdam.org/item/M2AN_1976__10_3_5_0.pdf

Duriscoe, D. M. (2016). Photometric indicators of visual night sky quality derived from all-sky brightness maps. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *181*, 33–45. https://doi.org/10.1016/j.jqsrt.2016.02.022

Duriscoe, D. M., Luginbuhl, C. B., & Moore, C. A. (2007). Measuring Night-Sky Brightness with a Wide-Field CCD Camera. *Publications of the Astronomical Society of the Pacific*, *119*(852), 192–213. https://doi.org/10.1086/512069

Elvidge, C. D., Baugh, K. E., Zhizhin, M., & Hsu, F.-C. (2013). Why VIIRS data are superior to DMSP for mapping nighttime lights. *Proceedings of the Asia-Pacific Advanced Network*, *35*, 62. https://doi.org/10.7125/APAN.35.7

Elvidge, C. D., Baugh, K., Zhizhin, M., Hsu, F. C., & Ghosh, T. (2017). VIIRS night-time lights. *International Journal of Remote Sensing*, *38*(21), 5860–5879. https://doi.org/10.1080/01431161.2017.1342050

Elvidge, C. D., Cinzano, P., Pettit, D. R., Arvesen, J., Sutton, P., Small, C., Nemani, R., Longcore, T., Rich, C., Safran, J., Weeks, J., & Ebener, S. (2007). The Nightsat mission concept. *International Journal of Remote Sensing*, *28*(12), 2645–2670. https://doi.org/10.1080/01431160600981525

Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C., Elvidge, C. D., Baugh, K., Portnov, B. A., Rybnikova, N. A., & Furgoni, R. (2016). The new world atlas of artificial night sky brightness. *Science Advances*, *2*(6), e1600377. https://doi.org/10.1126/sciadv.1600377

Falchi, F., Cinzano, P., Elvidge, C. D., Keith, D. M., & Haim, A. (2011). Limiting the impact of light pollution on human health, environment and stellar visibility. *Journal of Environmental Management*, *92*(10), 2714–2722. https://doi.org/10.1016/j.jenvman.2011.06.029

Fonken, L. K., & Nelson, R. J. (2014). The Effects of Light at Night on Circadian Clocks and Metabolism. *Endocrine Reviews*, *35*(4), 648–670. https://doi.org/10.1210/er.2013-1051

Franke, R. (1985). Thin plate splines with tension. *Computer Aided Geometric Design*, *2*(1–3), 87–95. https://doi.org/10.1016/0167-8396(85)90011-1

Gallaway, T. (2010). On Light Pollution, Passive Pleasures, and the Instrumental Value of Beauty. *Journal of Economic Issues*, *44*(1), 71–88. https://doi.org/10.2753/JEI0021-3624440104

Gallaway, T., Olsen, R. N., & Mitchell, D. M. (2010). The economics of global light pollution. *Ecological Economics*, *69*(3), 658–665. https://doi.org/10.1016/j.ecolecon.2009.10.003

Garstang, R. H. (1986). Model for Artificial Night-Sky Illumination. *Publications of the Astronomical Society of the Pacific*, *98*, 364. https://doi.org/10.1086/131768

Garstang, R. H. (1989). Night-sky brightness at observatories and sites. *Publications of the Astronomical Society of the Pacific*, *101*, 306. https://doi.org/10.1086/132436

Gaston, K. J., Bennie, J., Davies, T. W., & Hopkins, J. (2013). The ecological impacts of nighttime light pollution: A mechanistic appraisal: Nighttime light pollution. *Biological Reviews*, *88*(4), 912–927. https://doi.org/10.1111/brv.12036

Gaston, K. J., Davies, T. W., Bennie, J., & Hopkins, J. (2012). REVIEW: Reducing the ecological consequences of night-time light pollution: options and developments. *Journal of Applied Ecology*, *49*(6), 1256–1266. https://doi.org/10.1111/j.1365-2664.2012.02212.x

Gaston, K. J., Gaston, S., Bennie, J., & Hopkins, J. (2015). Benefits and costs of artificial nighttime lighting of the environment. *Environmental Reviews*, *23*(1), 14–23. https://doi.org/10.1139/er-2014-0041

Gaston, K. J., Visser, M. E., & Hölker, F. (2015). The biological impacts of artificial light at night: The research challenge. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1667), 20140133. https://doi.org/10.1098/rstb.2014.0133

Gsponer, A., & Hurni, J.-P. (2004). *Lanczos's functional theory of electrodynamics: A commentary on Lanczos's PhD dissertation*. https://doi.org/10.48550/ARXIV.MATH-PH/0402012

Hale, J. D., Davies, G., Fairbrass, A. J., Matthews, T. J., Rogers, C. D. F., & Sadler, J. P. (2013). Mapping Lightscapes: Spatial Patterning of Artificial Lighting in an Urban Landscape. *PLoS ONE*, *8*(5), e61460. https://doi.org/10.1371/journal.pone.0061460

Hänel, A., Posch, T., Ribas, S. J., Aubé, M., Duriscoe, D., Jechow, A., Kollath, Z., Lolkema, D. E., Moore, C., Schmidt, N., Spoelstra, H., Wuchterl, G., & Kyba, C. (2018). Measuring night sky brightness: Methods and challenges. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *205*, 278–290. https://doi.org/10.1016/j.jqsrt.2017.09.008

Harder, R. L., & Desmarais, R. N. (1972). Interpolation using surface splines. *Journal of Aircraft*, *9*(2), 189–191. https://doi.org/10.2514/3.44330

Hardy, J. W. (1998). *Adaptive optics for astronomical telescopes* (Vol. 16). Oxford Optical and Imaging Sci.

Hardy, R. L. (1990). Theory and applications of the multiquadric-biharmonic method 20 years of discovery 1968–1988. *Computers & Mathematics with Applications*, *19*(8–9), 163–208. https://doi.org/10.1016/0898-1221(90)90272-L

HCN. (2000). *Impact of outdoor lighting on man and nature*. HCN (Health Council of the Netherlands).

He, Y., Chen, C., Zhang, J., Liu, J., He, F., Wang, C., & Du, B. (2021). *Visual Semantics Allow for Textual Reasoning Better in Scene Text Recognition*. https://doi.org/10.48550/ARXIV.2112.12916

Hofierka, J. (2005). Interpolation of Radioactivity Data Using Regularized Spline with Tension. *Applied GIS*, *1*(2). https://doi.org/10.2104/ag050016

Hofierka, J., & Cebecauer, T. (2007). Spatial Interpolation of Elevation Data With Variable Density: A New Methodology to Derive Quality DEMs. *IEEE Geoscience and Remote Sensing Letters*, *4*(1), 117–121. https://doi.org/10.1109/LGRS.2006.887055

Hofierka, J., Cebecauer, T., & Šúri, M. (2007). Optimisation of Interpolation Parameters Using Cross-validation. In R. J. Peckham & G. Jordan (Eds.), *Digital Terrain Modelling* (pp. 67–82). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-36731-4_3

Hofierka, J., Parajka, J., Mitasova, H., & Mitas, L. (2002). Multivariate Interpolation of Precipitation Using Regularized Spline with Tension. *Transactions in GIS*, *6*(2), 135–150. https://doi.org/10.1111/1467-9671.00101

Hölker, F., Moss, T., Griefahn, B., Kloas, W., Voigt, C. C., Henckel, D., Hänel, A., Kappeler, P. M., Völker, S., Schwope, A., & others. (2010). The dark side of light: A transdisciplinary research agenda for light pollution policy. *Ecology and Society*, *15*(4).

Hsu, F.-C., Baugh, K., Ghosh, T., Zhizhin, M., & Elvidge, C. (2015). DMSP-OLS Radiance Calibrated Nighttime Lights Time Series with Intercalibration. *Remote Sensing*, *7*(2), 1855–1876. https://doi.org/10.3390/rs70201855

Hu, Y., & Li, W. (2017). *Spatial Data Infrastructures*. https://doi.org/10.48550/ARXIV.1707.03969

Hutchinson, M. F. (1989). A new procedure for gridding elevation and stream line data with automatic removal of spurious pits. *Journal of Hydrology*, *106*(3–4), 211–232. https://doi.org/10.1016/0022-1694(89)90073-5

Hutchinson, M. F. (1998). Interpolation of rainfall data with thin plate smoothing splines. Part I: Two dimensional smoothing of data with short range correlation. In *Journal of Geographic Information and Decision …*. researchgate.net. https://www.researchgate.net/profile/Mf-Hutchinson/publication/2570048_Interpolation_of_Rainfall_Data_with_Thin_Plate_Smoothing_Splines_-_Part_I_Two_Dimensional_Smoothing_of_Data_with_Short_Range_Correlation/links/02e7e52d2414a17fe6000000/Interpolation-of-Rainfall-Data-with-Thin-Plate-Smoothing-Splines-Part-I-Two-Dimensional-Smoothing-of-Data-with-Short-Range-Correlation.pdf

Hutchinson, M. F., & Gessler, P. E. (1994). Splines—More than just a smooth interpolator. *Geoderma*, *62*(1–3), 45–67. https://doi.org/10.1016/0016-7061(94)90027-2

IDSA. (2017). Light Pollution. In *International Dark-Sky Association*. https://www.darksky.org/light-pollution/

Jassim, F. A. (2013). *Kriging Interpolation Filter to Reduce High Density Salt and Pepper Noise*. https://doi.org/10.48550/ARXIV.1302.1300

Jassim, F. A., & Altaany, F. H. (2013). *Image Interpolation Using Kriging Technique for Spatial Data*. https://doi.org/10.48550/ARXIV.1302.1294

Jechow, A., Hölker, F., Kolláth, Z., Gessner, M. O., & Kyba, C. (2016). Evaluating the summer night sky brightness at a research field site on Lake Stechlin in northeastern Germany. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *181*, 24–32. https://doi.org/10.1016/j.jqsrt.2016.02.005

Jechow, A., Kyba, C., & Hölker, F. (2019). Beyond All-Sky: Assessing Ecological Light Pollution Using Multi-Spectral Full-Sphere Fisheye Lens Imaging. *Journal of Imaging*, *5*(4), 46. https://doi.org/10.3390/jimaging5040046

Jechow, A., Ribas, S. J., Domingo, R. C., Hölker, F., Kolláth, Z., & Kyba, C. (2018). Tracking the dynamics of skyglow with differential photometry using a digital camera with fisheye lens. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *209*, 212–223. https://doi.org/10.1016/j.jqsrt.2018.01.032

Jeffrey, S. J., Carter, J. O., Moodie, K. B., & Beswick, A. R. (2001). Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environmental Modelling & Software*, *16*(4), 309–330. https://doi.org/10.1016/S1364-8152(01)00008-1

Kiwelekar, A. W., Mahamunkar, G. S., Netak, L. D., & Nikam, V. B. (2020). *Deep Learning Techniques for Geospatial Data Analysis*. https://doi.org/10.48550/ARXIV.2008.13146

Krisciunas, K., & Schaefer, B. E. (1991). A model of the brightness of moonlight. *Publications of the Astronomical Society of the Pacific*, *103*, 1033. https://doi.org/10.1086/132921

Kuechly, H. U., Kyba, C., Ruhtz, T., Lindemann, C., Wolter, C., Fischer, J., & Hölker, F. (2012). Aerial survey and spatial analysis of sources of light pollution in Berlin, Germany. *Remote Sensing of Environment*, *126*, 39–50. https://doi.org/10.1016/j.rse.2012.08.008

Kyba, C., Garz, S., Kuechly, H., De Miguel, A., Zamorano, J., Fischer, J., & Hölker, F. (2014). High-Resolution Imagery of Earth at Night: New Sources, Opportunities and Challenges. *Remote Sensing*, *7*(1), 1–23. https://doi.org/10.3390/rs70100001

Kyba, C., Kuester, T., Sánchez De Miguel, A., Baugh, K., Jechow, A., Hölker, F., Bennie, J., Elvidge, C., Gaston, K. J., & Guanter, L. (2017). Artificially lit surface of Earth at night increasing in radiance and extent. *Science Advances*, *3*(11), e1701528. https://doi.org/10.1126/sciadv.1701528

Kyba, C., Ruhtz, T., Fischer, J., & Hölker, F. (2011). Cloud Coverage Acts as an Amplifier for Ecological Light Pollution in Urban Ecosystems. *PLoS ONE*, *6*(3), e17307. https://doi.org/10.1371/journal.pone.0017307

Kyba, C., Tong, K. P., Bennie, J., Birriel, I., Birriel, J. J., Cool, A., Danielsen, A., Davies, T. W., Outer, P. N. D., Edwards, W., Ehlert, R., Falchi, F., Fischer, J., Giacomelli, A., Giubbilini, F., Haaima, M., Hesse, C., Heygster, G., Hölker, F., … Gaston, K. J. (2015). Worldwide variations in artificial skyglow. *Scientific Reports*, *5*(1), 8409. https://doi.org/10.1038/srep08409

Le, V. D., & Cha, S. K. (2018). *Real-time Air Pollution prediction model based on Spatiotemporal Big data*. https://doi.org/10.48550/ARXIV.1805.00432

Le, V.-D., Bui, T.-C., & Cha, S. K. (2019). *Spatiotemporal deep learning model for citywide air pollution interpolation and prediction*. https://doi.org/10.48550/ARXIV.1911.12919

Li, J., Heap, A. D., Potter, A., & Daniell, J. J. (2011). Application of machine learning methods to spatial interpolation of environmental variables. *Environmental Modelling & Software*, *26*(12), 1647–1659. https://doi.org/10.1016/j.envsoft.2011.07.004

Li, X., Li, D., Xu, H., & Wu, C. (2021). Intercalibration between DMSP/OLS and VIIRS night-time light images to evaluate city light dynamics of Syria's

major human settlement during Syrian Civil War. In *Remote Sensing of Night-Time Light* (pp. 80–97). Routledge.

Li, X., Zhou, Y., Asrar, G. R., Imhoff, M., & Li, X. (2017). The surface urban heat island response to urban expansion: A panel analysis for the conterminous United States. *Science of The Total Environment*, *605–606*, 426–435. https://doi.org/10.1016/j.scitotenv.2017.06.229

Li, Y., Wang, W., Deng, K., & Liu, J. S. (2020). *Stratification and Optimal Resampling for Sequential Monte Carlo*. https://doi.org/10.48550/ARXIV.2004.01975

Liang, Y., Zhu, J., Ye, W., & Gao, S. (2022). *Region2Vec: Community Detection on Spatial Networks Using Graph Embedding with Node Attributes and Spatial Interactions*. https://doi.org/10.48550/ARXIV.2210.08041

Lolkema, D. E., Haaima, M., Den Outer, P. N., & Spoelstra, H. (2011). *Effects of meteorological and atmospheric conditions on night sky brightness*. 117–127. https://doi.org/10.2495/RAV110121

Longcore, T., & Rich, C. (2004). Ecological light pollution. *Frontiers in Ecology and the Environment*, *2*(4), 191–198. https://doi.org/10.1890/1540-9295(2004)002[0191:ELP]2.0.CO;2

Longcore, T., Rich, C., Mineau, P., MacDonald, B., Bert, D. G., Sullivan, L. M., Mutrie, E., Gauthreaux, S. A., Avery, M. L., Crawford, R. L., Manville, A. M., Travis, E. R., & Drake, D. (2013). Avian mortality at communication towers in the United States and Canada: Which species, how many, and where? *Biological Conservation*, *158*, 410–419. https://doi.org/10.1016/j.biocon.2012.09.019

Lu, R. (2022). *Application of Co-Kriging and Ordinary Kriging for Selecting Additional Well Locations*. https://doi.org/10.48550/ARXIV.2203.12164

Luginbuhl, C. B., Duriscoe, D. M., Moore, C. W., Richman, A., Lockwood, G. W., & Davis, D. R. (2009). From the Ground Up II: Sky Glow and Near-Ground Artificial Light Propagation in Flagstaff, Arizona. *Publications of the Astronomical Society of the Pacific*, *121*(876), 204–212. https://doi.org/10.1086/597626

Luginbuhl, C. B., Walker, C. E., & Wainscoat, R. J. (2009). Lighting and astronomy. *Physics Today*, *62*(12), 32–37. https://doi.org/10.1063/1.3273014

Lutsai, K., & Lampert, C. H. (2023). *Geolocation Predicting of Tweets Using BERT-Based Models*. https://doi.org/10.48550/ARXIV.2303.07865

Lyytimäki, J. (2013). Nature's nocturnal services: Light pollution as a non-recognised challenge for ecosystem services research and management. *Ecosystem Services*, *3*, e44–e48. https://doi.org/10.1016/j.ecoser.2012.12.001

Madhukar, B. N., & Narendra, R. (2013). Lanczos Resampling for the Digital Processing of Remotely Sensed Images. In V. S. Chakravarthi, Y. J. M. Shirur, & R. Prasad (Eds.), *Proceedings of International Conference on VLSI, Communication, Advanced Devices, Signals & Systems and Networking (VCASAN-2013)* (Vol. 258, pp. 403–411). Springer India. https://doi.org/10.1007/978-81-322-1524-0_48

Maeng, S. J., Ozdemir, O., Guvenc, I., & Sichitiu, M. L. (2023). *Kriging-Based 3-D Spectrum Awareness for Radio Dynamic Zones Using Aerial Spectrum Sensors*. https://doi.org/10.48550/ARXIV.2307.06310

Mai, G., Jiang, C., Sun, W., Zhu, R., Xuan, Y., Cai, L., Janowicz, K., Ermon, S., & Lao, N. (2022). *Towards General-Purpose Representation Learning of Polygonal Geometries*. https://doi.org/10.48550/ARXIV.2209.15458

Metha, B., Trenti, M., Chu, T., & Battisti, A. (2022). *A geostatistical analysis of multiscale metallicity variations in galaxies [II]: Predicting the metallicities of Hii and diffuse ionised gas regions via universal kriging*. https://doi.org/10.48550/ARXIV.2205.13314

Metheron, G. (1971). Theory of regionalized variables and its applications. In *Cah. Centre Morrphol. Math.* cir.nii.ac.jp. https://cir.nii.ac.jp/crid/1571698599412839424

Miller, S. D., Mills, S. P., Elvidge, C. D., Lindsey, D. T., Lee, T. F., & Hawkins, J. D. (2012). Suomi satellite brings to light a unique frontier of nighttime environmental sensing capabilities. *Proceedings of the National Academy*

of Sciences, *109*(39), 15706–15711. https://doi.org/10.1073/pnas.1207034109

Miller, S., Straka, W., Mills, S., Elvidge, C., Lee, T., Solbrig, J., Walther, A., Heidinger, A., & Weiss, S. (2013). Illuminating the Capabilities of the Suomi National Polar-Orbiting Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band. *Remote Sensing*, *5*(12), 6717–6766. https://doi.org/10.3390/rs5126717

Mitáš, L., & Mitášová, H. (1988). General variational approach to the interpolation problem. *Computers & Mathematics with Applications*, *16*(12), 983–992. https://doi.org/10.1016/0898-1221(88)90255-6

Mitas, L., & Mitasova, H. (1999). Spatial Interpolation. In P. Longley, M. F. Goodchild, D. J. Maguire, & D. W. Rhind (Eds.), *Geographical Information Systems: Principles, Techniques, Management and Applications* (pp. 481–492). GeoInformation International, Wiley.

Mitášová, H., & Hofierka, J. (1993). Interpolation by regularized spline with tension: II. Application to terrain modeling and surface geometry analysis. *Mathematical Geology*, *25*(6), 657–669. https://doi.org/10.1007/BF00893172

Mitášová, H., & Mitáš, L. (1993). Interpolation by regularized spline with tension: I. Theory and implementation. *Mathematical Geology*, *25*(6), 641–655. https://doi.org/10.1007/BF00893171

Mitasova, H., Mitas, L., Brown, W. M., Gerdes, D. P., Kosinovsky, I., & Baker, T. (1995). Modelling spatially and temporally distributed phenomena: New methods and tools for GRASS GIS. *International Journal of Geographical Information Systems*, *9*(4), 433–446. https://doi.org/10.1080/02693799508902048

Neteler, M., & Mitasova, H. (2002). *Open Source GIS: A GRASS GIS Approach* (Vol. 689). Springer US. https://doi.org/10.1007/978-1-4757-3578-9

Oliver, M. A., & Webster, R. (1990). Kriging: A method of interpolation for geographical information systems. *International Journal of Geographical Information Systems*, *4*(3), 313–332. https://doi.org/10.1080/02693799008941549

Oliver, M. A., & Webster, R. (2014). A tutorial guide to geostatistics: Computing and modelling variograms and kriging. *CATENA*, *113*, 56–69. https://doi.org/10.1016/j.catena.2013.09.006

Palar, P. S., & Shimoyama, K. (2018). *On efficient global optimization via universal Kriging surrogate models*. https://doi.org/10.48550/ARXIV.1803.08667

Posch, T., Binder, F., & Puschnig, J. (2018). Systematic measurements of the night sky brightness at 26 locations in Eastern Austria. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *211*, 144–165. https://doi.org/10.1016/j.jqsrt.2018.03.010

Pun, C. S. J., & So, C. W. (2012). Night-sky brightness monitoring in Hong Kong: A city-wide light pollution assessment. *Environmental Monitoring and Assessment*, *184*(4), 2537–2557. https://doi.org/10.1007/s10661-011-2136-1

Redzuan Tahar, M., Kamarudin, F., Umar, R., Khairul Amri Kamarudin, M., Hazmin Sabri, N., Ahmad, K., Abdul Rahim, S., & Sharul Aikal Baharim, M. (2017). Spatial Model of Sky Brightness Magnitude in Langkawi Island, Malaysia. *Research in Astronomy and Astrophysics*, *17*(4), 037. https://doi.org/10.1088/1674-4527/17/4/37

Rich, C., & Longcore, T. (2006). Ecological Consequences of Artificial Night Lighting. In *Bibliovault OAI Repository, the University of Chicago Press*.

Rivera, R. (2019). *A Low Rank Gaussian Process Prediction Model for Very Large Datasets*. https://doi.org/10.48550/ARXIV.1906.03564

Rivoirard, J. (1994). *Introduction to disjunctive kriging and non-linear geostatistics*. Clarendon Press ; Oxford University Press.

Riza, L. S., Izzuddin, A., Utama, J. A., Samah, K. A. F. A., Herdiwijaya, D., Hidayat, T., Anugraha, R., & Mumpuni, E. S. (2022). Data analysis techniques in light pollution: A survey and taxonomy. *New Astronomy Reviews*, *95*, 101663. https://doi.org/10.1016/j.newar.2022.101663

Rouhani, S., & Myers, D. E. (1990). Problems in space-time kriging of geohydrological data. *Mathematical Geology*, *22*(5), 611–623. https://doi.org/10.1007/BF00890508

Salmon, M. (2003). Artificial night lighting and sea turtles. *Biologist, 50*, 163–168.

Sánchez De Miguel, A., Aubé, M., Zamorano, J., Kocifaj, M., Roby, J., & Tapia, C. (2017). Sky Quality Meter measurements in a colour-changing world. *Monthly Notices of the Royal Astronomical Society*, *467*(3), 2966–2979. https://doi.org/10.1093/mnras/stx145

Šimonová, D., & Tichý, P. (2021). *When does the Lanczos algorithm compute exactly?* https://doi.org/10.48550/ARXIV.2106.02068

Sommerville, I. (2011). *Software Engineering*. Addison-Wesley.

Srivastava, H., & Isaaks, E. (1989). An introduction to applied geostatistics. In *Oxford: University Press*.

Stevens, R. G., Brainard, G. C., Blask, D. E., Lockley, S. W., & Motta, M. E. (2013). Adverse Health Effects of Nighttime Lighting. *American Journal of Preventive Medicine*, *45*(3), 343–346. https://doi.org/10.1016/j.amepre.2013.04.011

Stewart, A. J., Robinson, C., Corley, I. A., Ortiz, A., Ferres, J. M. L., & Banerjee, A. (2021). *TorchGeo: Deep Learning With Geospatial Data*. https://doi.org/10.48550/ARXIV.2111.08872

Strandberg, J., de Luna, S. S., & Mateu, J. (2018). *Prediction of spatial functional random processes: Comparing functional and spatio-temporal kriging approaches*. https://doi.org/10.48550/ARXIV.1802.05761

Sun, H., & Chen, J. (2022). *Propagation Map Reconstruction via Interpolation Assisted Matrix Completion*. https://doi.org/10.48550/ARXIV.2207.13473

Thums, M., Whiting, S. D., Reisser, J., Pendoley, K. L., Pattiaratchi, C. B., Proietti, M., Hetzel, Y., Fisher, R., & Meekan, M. G. (2016). Artificial light on water attracts turtle hatchlings during their near shore transit. *Royal Society Open Science*, *3*(5), 160142. https://doi.org/10.1098/rsos.160142

Tomczak, M. (1998). Spatial interpolation and its uncertainty using automated anisotropic inverse distance weighting (IDW)-cross-validation/jackknife approach. In *Journal of Geographic Information and Decision …*. wiki.leg.ufpr.br.

http://www.wiki.leg.ufpr.br/lib/exe/fetch.php/disciplinas:geoesalq:edercomunello-artigo2.pdf

Tsitsigkos, D., Lampropoulos, K., Bouros, P., Mamoulis, N., & Terrovitis, M. (2020). *A Two-level Spatial In-Memory Index*. https://doi.org/10.48550/ARXIV.2005.08600

Wahba, G. (1990). *Spline Models for Observational Data*. Society for Industrial and Applied Mathematics. https://doi.org/10.1137/1.9781611970128

Walker, C. E., & Pompea, S. M. (2011). *National education program for energy efficient illumination engineering* (P. Ambs, D. Curticapean, C. Emmelmann, W. Knapp, Z. T. Kuznicki, & P. P. Meyrueis, Eds.; p. 80650Q). https://doi.org/10.1117/12.884914

Walker, M. F. (1973). Light Pollution in California and Arizona. *Publications of the Astronomical Society of the Pacific*, *85*, 508. https://doi.org/10.1086/129496

Watson, G. L., Jerrett, M., Reid, C. E., & Telesca, D. (2021). *Treeging*. https://doi.org/10.48550/ARXIV.2110.01053

Webber, R. J. (2019). *Unifying Sequential Monte Carlo with Resampling Matrices*. https://doi.org/10.48550/ARXIV.1903.12583

Witte, N. S., & Bessis, D. (1999). The Lanczos algorithm for extensive many-body systems in the thermodynamic limit. *Journal of Mathematical Physics*, *40*(10), 4975–4994. https://doi.org/10.1063/1.533010

Wu, B., & Wong, H. (2012). VISUALIZATION AND ANALYSIS OF LIGHT POLLUTION: A CASE STUDY IN HONG KONG. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *I–2*, 171–176. https://doi.org/10.5194/isprsannals-I-2-171-2012

Zamorano, J., Sánchez De Miguel, A., Ocaña, F., Pila-Díez, B., Gómez Castaño, J., Pascual, S., Tapia, C., Gallego, J., Fernández, A., & Nievas, M. (2016). Testing sky brightness models against radial dependency: A dense two dimensional survey around the city of Madrid, Spain. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *181*, 52–66. https://doi.org/10.1016/j.jqsrt.2016.02.029

Zawish, M., Dharejo, F. A., Khowaja, S. A., Dev, K., Davy, S., Qureshi, N. M. F., & Bellavista, P. (2022). *AI and 6G into the Metaverse: Fundamentals, Challenges and Future Research Trends*. https://doi.org/10.48550/ARXIV.2208.10921

Zhan, W., & Datta, A. (2023). *Neural networks for geospatial data*. https://doi.org/10.48550/ARXIV.2304.09157

Zhu, M., Murphy, K., & Jonschkowski, R. (2020). *Towards Differentiable Resampling*. https://doi.org/10.48550/ARXIV.2004.11938