To: Mr. Heru Budi Hartono, Governor of Jakarta Province
Subject: Evidence based approach for pollution control policy across Kecamatans in Jakarta

Introduction

In 2021, the Indonesian government announced the relocation of its capital city to Nusantara, largely due to escalating traffic and pollution risks. This relocation reduces Jakarta Province's fund to manage pollution risks due to disappearance of the substantial funding previously received as the capital city. This memo presents evidence-based policy recommendations for pollution control in Jakarta's Kecamatans. It is vital to utilize data-driven approaches to optimize resource allocation and maximize impact[1].

The Jakarta Environmental Agency reports that the city's air quality often falls below the national air quality standard[2]. The IQAir consistently ranks Jakarta among the cities with the poorest air quality in the world[3]. Ground-level pollution, especially Particulate Matter, has significant health impacts, as evidenced by the 2020 U.S. EPA data showing damages of $1.768 trillion from over 230,000 incidents[4].

Based on an evidence-based policy approach, it's crucial to prioritize regions with high vulnerability, assessed through exposure, sensitivity, and adaptive capacity metrics: pollution level increases (exposure), affected population size (sensitivity), and medical facility capability to address pollution-related health issues (adaptive capacity)[5].

Methodology

To determine each region's exposure and sensitivity to pollution, an assessment of population density and the absolute increase in pollution was conducted. The increase in pollution was calculated from the difference between ground level particulate matter levels in 2022 and 2002, as shown in Maps 1 and 2, using data from Washington University in St. Louis (WUSTL). The difference was then averaged at Kecamatan level.

The population density was obtained by dividing the population in each Kelurahan by its area. Population across Kelurahan in Jakarta was obtained from Jakarta Open Data, which shows

[1] Yu, J., Castellani, K., Forysinski, K. *et al.* Geospatial indicators of exposure, sensitivity, and adaptive capacity to assess neighbourhood variation in vulnerability to climate change-related health hazards. *Environ Health* **20**, 31 (2021). https://doi.org/10.1186/s12940-021-00708-z

[2] ANTARA News. (2023.). Kualitas udara DKI Jakarta terburuk ketiga di dunia. Retrieved [December 2023], from https://www.antaranews.com/berita/3727701/kualitas-udara-dki-jakarta-terburuk-ketiga-di-dunia

[3] Chen, Heather. (2023). Jakarta is the world's most polluted city. And Indonesia's leader may have the cough to prove it. *CNN*. Retrieved [December 2023] from https://www.cnn.com/2023/08/16/asia/indonesia-pollution-jokowi-cough-intl-hnk/index.html

[4] U.S. Environmental Protection Agency, Office of Air and Radiation. (2011). The Benefits and Costs of the Clean Air Act from 1990 to 2020: Final Report – Rev. A. https://www.epa.gov.

[5] Penn State University. (n.d.). Vulnerability's Three Dimensions Introduction. Coastal Processes, Hazards, and Society. Retrieved [December 2023], from https://www.e-education.psu.edu/earth107/node/707

how many people live in each Kelurahan in 2021 based on identity card data. The area of each Kelurahan was obtained from measurements done in ArcGIS software. Finally, dividing the population in each Kelurahan by its area results in population density as shown in Map 3.

High population density results in greater sensitivity to pollution risk, and a high pollution increase indicates high exposure. Both parameters were compared to identify Kecamatans with both high exposure and sensitivity, as shown in Map 4.

Adaptive capacity was assessed by calculating the number of people covered by each medical facility, including hospitals and clinics, in each Kecamatan. The number of medical facilities in each Kecamatan will be used as the denominator while the population in respected Kecamatan will be the nominator. This calculation represents the burden of each medical facility, serving as a proxy for the adaptive capacity of each Kecamatan.

Results

Pollution tends to increase in Kecamatan that located in the outskirts of Jakarta, which are the 4 southernmost, 3 easternmost, and 1 westernmost Kecamatan, as colored red in Map 4. There might be a correlation between pollution increase and proximity to central Jakarta, possibly due to government focus on mitigating pollution in this region.

On the other side, there is no clear spatial pattern of the population density as shown in Map 4. From the map, one might argue that population lives more in the central of Jakarta, however spatial analysis alone cannot create this conclusion. However, areas such as Senayan and Taman Mini public parks, and a swamp in the northwest, show significantly lower density.

From the interaction between population density and the increase in pollution, the research concluded that areas with the highest pollution exposure and sensitivity are in the south which are Kecamatan Ciracas and Kecamatan Pasar Rebo, and the west which is Kecamatan Kalideres. Slightly less exposed but still considerable areas are in the south (Kecamatan Cipayung and Jagakarsa) and east (Kecamatan Kelapa Gading, Cilincing, and Cakung).

Adaptive capacity towards risk of pollution has spatial pattern which could be observable from Map 5, which is the region whose medical facility have the least people to serve are located close to the central of Jakarta. This correlation is analog to pollution increase, which might also be explained by the same reason. Region whose medical facility have the largest population to serve, descending from the largest, are located in the east, which are Kecamatan Cakung and Kecamatan Duren Sawit, the north, which is Kecamatan Koja, and in the west, Kecamatan Kebon Jeruk.

Based on previous findings, Kecamatan Cakung shows high exposure, high sensitivity, and low adaptive capacity. Kecamatan Cakung could be seen as an outlier in terms of adaptive capacity, since the mean of the burden is 7,900 while the median is 6,200 people per medical facility shown by the histogram in Figure 1. In addition, Kecamatan Cakung also one of worst

Kecamatan in terms of sensitivity with close to 600,000 people live in this Kecamatan, shown by the dot in the upper-right red area in Figure 2.

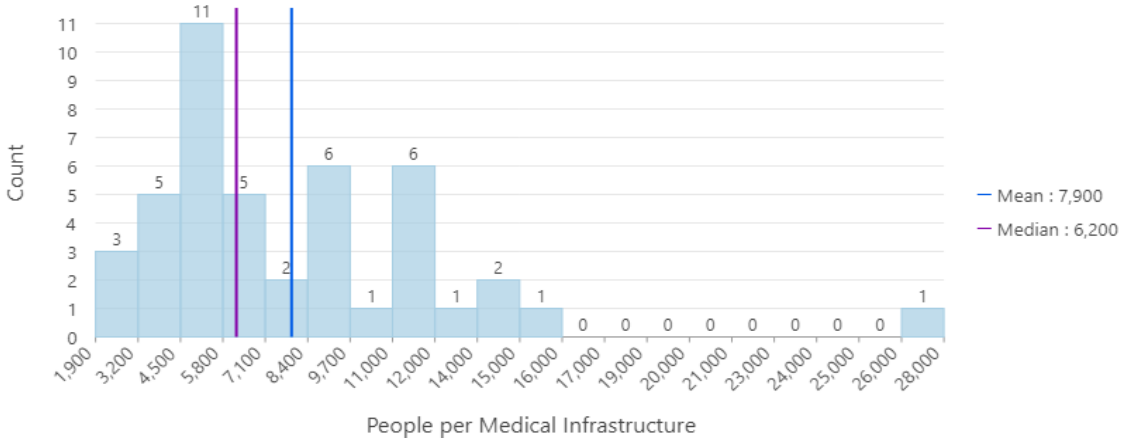


Figure 1 Histogram of Kecamatan with people per medical facility

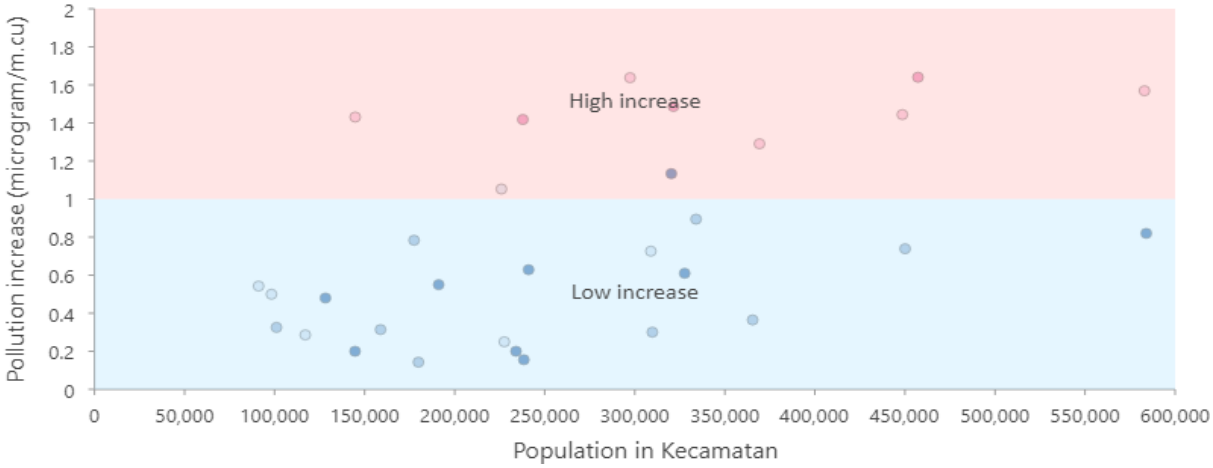


Figure 2 Pollution exposure and sensitivity

Assumptions

- The capacity and quality of medical facility are assumed to be uniform across Kecamatan. Further analysis needs to be done by incorporating information on each facility's capacity.
- The people do not necessary will and have to come to the medical facility located in their Kecamatan. An argument can also be made that each patient might choose a medical service located the closest to their premises, which does not necessarily mean to be their Kecamatans medical facility. This will probably happen to the population living close to the border. This bias can also happen in the outermost Jakarta boundary. However, there is no data available for medical facility close to the border of Jakarta.
- Population data only consider individuals with Jakarta ID cards, potentially omitting non-registered residents.
- The analysis assumes that people are primarily affected by pollution in their residential area, not considering workday commuting.

Conclusion

Jakarta government should focus its pollution related measure to Kecamatan Cakung, located in East Jakarta. There are close to 600,000 people living in this Kecamatan, while having the worst adaptive capacity in Jakarta, because this massive population have not been supported by sufficient medical facilities. Further analysis should be done to definitively recommend specific budget allocation for this Kecamatan relative to other Kecamatans.

Technical Appendix

Data Sources:

- Open Street Map, 2017, 4. Batas Administrasi Kelurahan DKI Jakarta (Geopackage (.gpkg) Format), from https://drive.google.com/file/d/18N6_1o5FR1wlBkubrzm-ZTnRMUleUqCe/view
- Open Street Map, 2017, Hospital, 7. Fasilitas Kesehatan (Shapefile Format) (Shapefile format), from https://drive.google.com/drive/folders/1lwcuW9RCcR18IzI_ad1P0azZqvGz5_P8
- Open Street Map, 2017, Clinics, 7. Fasilitas Kesehatan (Shapefile Format) (Shapefile format), from https://drive.google.com/drive/folders/1lwcuW9RCcR18IzI_ad1P0azZqvGz5_P8
- Jakarta Open Data, 2020, Jakarta population across Kelurahan in 2021 CSV, from https://data.jakarta.go.id/dataset/datadkimenurutkepadatanpenduduk
- Washington University in St. Louis. (2000-2022). Satellite-derived PM2.5 Archive. Atmospheric Composition Analysis Group. Retrieved [December 2023], from https://sites.wustl.edu/acag/datasets/surface-pm2-5-archive/#V5.GL.03

Description of Technical Process:

Identifying the pollution level starts with creating a raster layer from NetCDF raw data downloaded from the Washington University website. Creation of raster layers was done using “Make NetCDF Raster Layer” tools in ArcGIS. These raster layers show the satellite observation on annual average of ground level particulate matter across the world with granularity of 0.01 x 0.01 degree, or around 1 x 1 km in the equatorial region. This data has been calibrated with the actual ground level observation in several observation stations. Finally, the raster calculator tool was used to create another raster which shows the difference between pollution level in 2022 and 2002. The difference raster will be used as the proxy of spatial distribution of pollution increase in Jakarta, as shown in Map 2.

Another data required for analyzing the exposure to pollution is how many people would be impacted by the pollution increase. Population across Kelurahan in Jakarta was obtained from Jakarta Open Data website in a csv format, while the spatial data of Kelurahan boundary was obtained from Jakarta Open Street Map community website. The former will be joined to the later, with the name of Kelurahan as the join features. However, there are two discrepancies in the formatting of Kelurahan field, the first is whether to use space or not in the name, and the

capitalization of the alphabet, as seen in Table 1. The difference in space need to be solved manually by editing the population csv file in Excel, while the capitalization problem was solved in ArcGIS using the Field Calculator tool by using !*name!.upper()* expression.

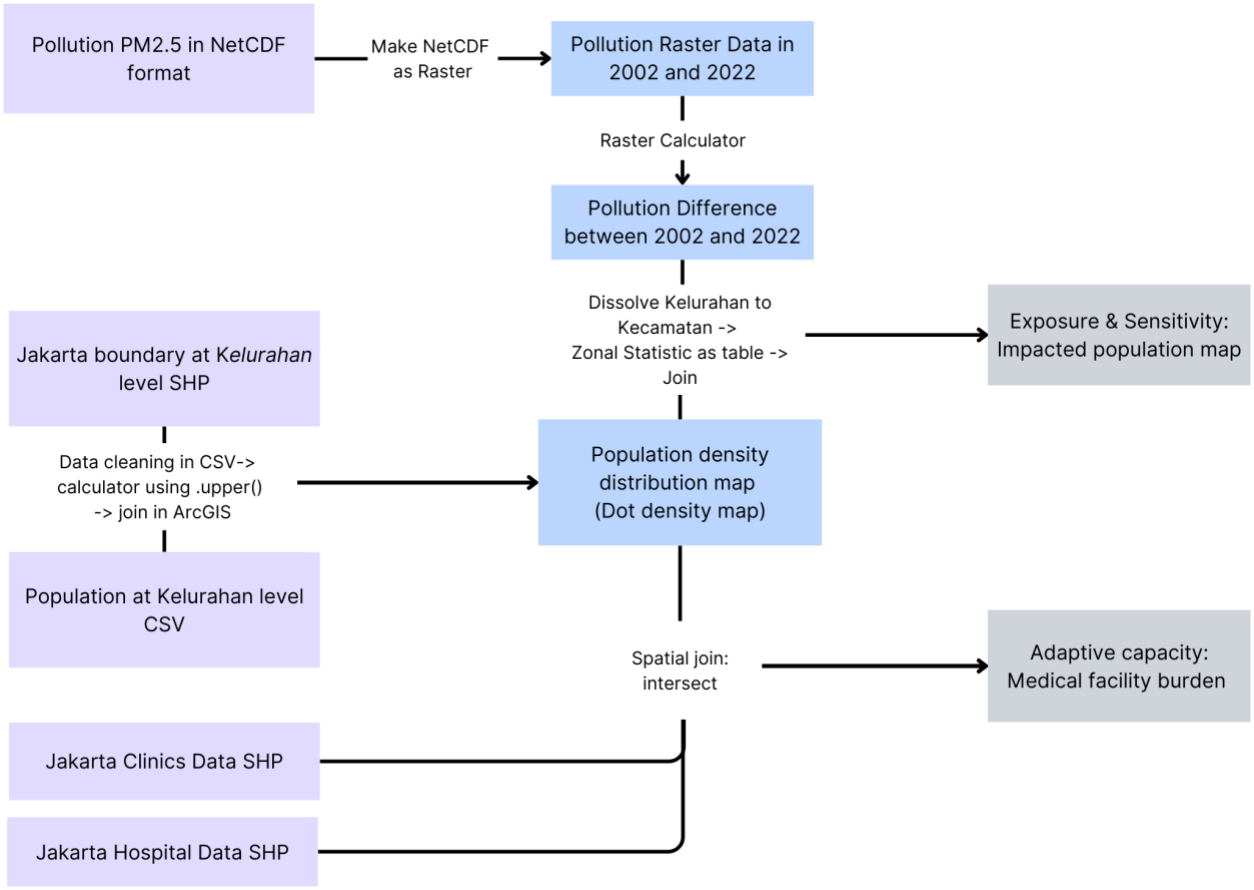
The interaction between population density and pollution increase should be analyze by visualizing it using Bivariate method in symbology as shown by Map 4. The mean of pollution increase/decrease can be obtained by using Zonal Statistic to Table tools, which will calculate the Mean, Median, Max, Min, etc. of the pollution level which intersect with each Kecamatan. Kecamatan was used in this matter because the satellite observation is too granular to be analyzed by the tool in several Kelurahan whose area is relatively small. The mean field will be used to estimate the level of pollution in each Kecamatan. This data will then be one of the inputs alongside the population density for the bivariate analysis. The red region means the pollution has increased, while green is the opposite. On the other hand, the darker the color, means the population density is greater. Therefore, the region with the greatest exposure would be the dark red as explained by the legend.

Finally, the sensitivity data was calculated by counting how many people are covered by one medical facility. This analysis was started with counting how many medical facilities was available in each Kecamatan. The counting was done by applying Spatial Join tools with the Kecamatan layer as the main features and medical facility (hospital and clinic) as the input features. There will be two counting field, one for the hospital and the other for clinics. Field calculator is used to add the counting of hospitals and the clinics. Finally, the burden ratio was calculated by dividing the number of medical facilities in each Kecamatan to each Kecamatans number of populations. The higher the number means another medical facility might be needed by the Kecamatan.

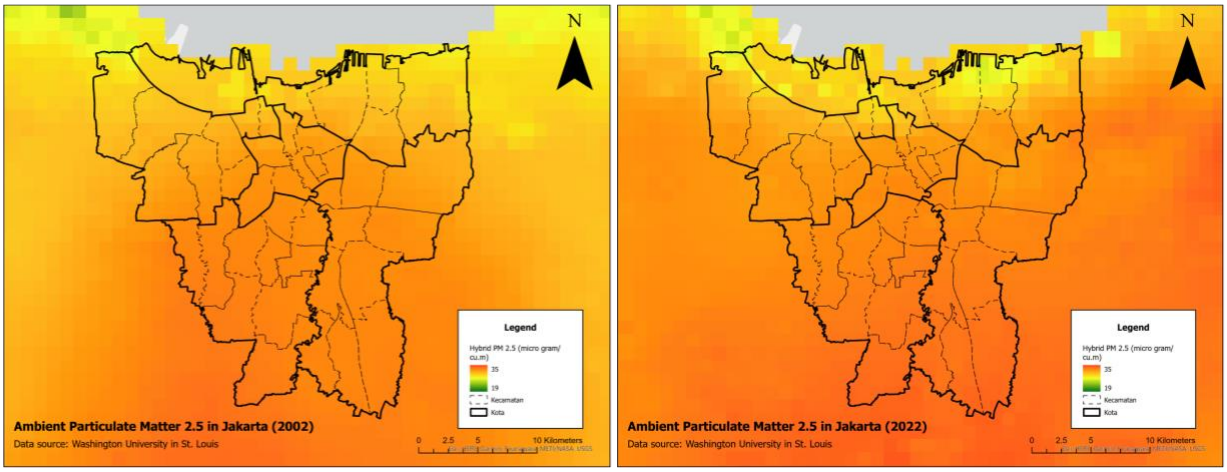
Table 1 Name discrepancies between the population data and Kelurahan boundary data

Name in Kelurahan Boundary	**Name in Population Data**
KRENDANG	Kerendang
BALEKAMBANG	Bale Kambang
KAMPUNG RAWA	Kampung Tengah
KRAMATJATI	Kramat Jati
KALIBARU	Kali Baru
PINANGRANTI	Pinang Ranti
RAWAJATI	Rawa Jati
JATIPULO	Jati Pulo
PALMERIAM	Pal Meriam

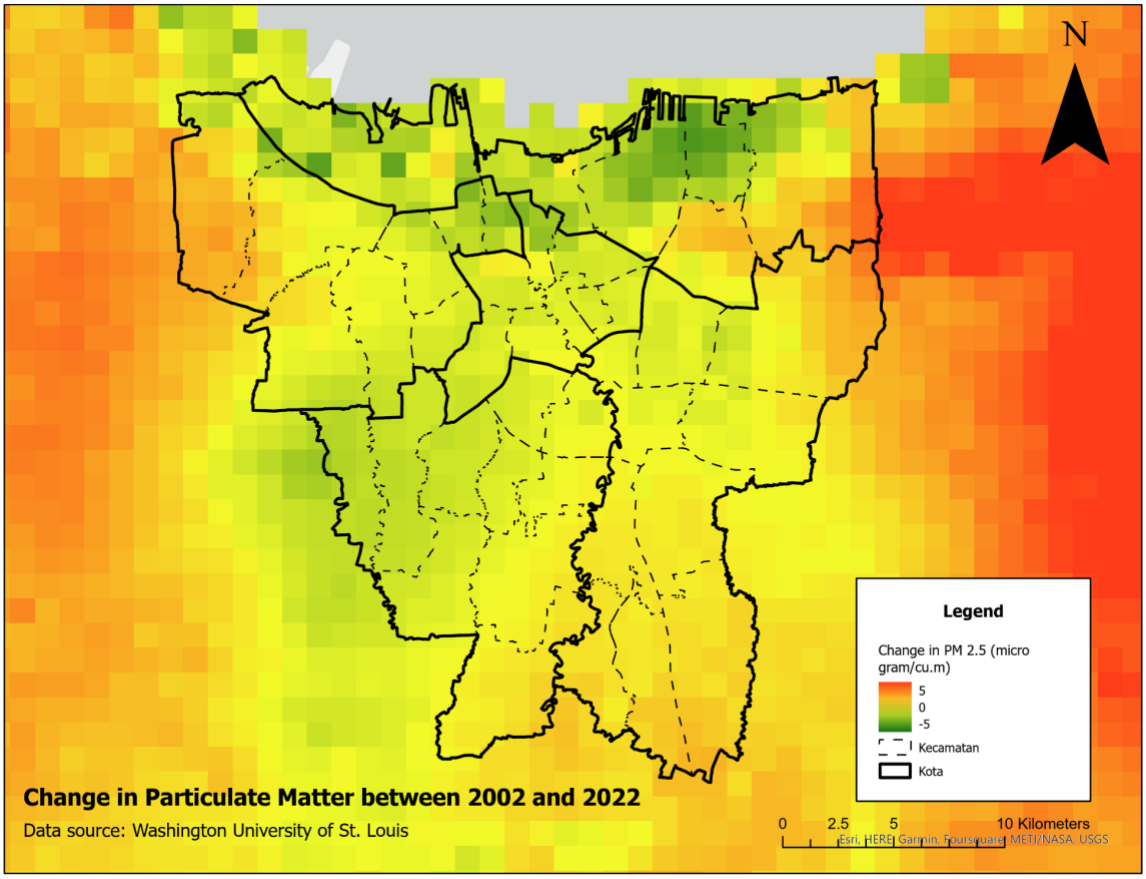
GIS Process Map



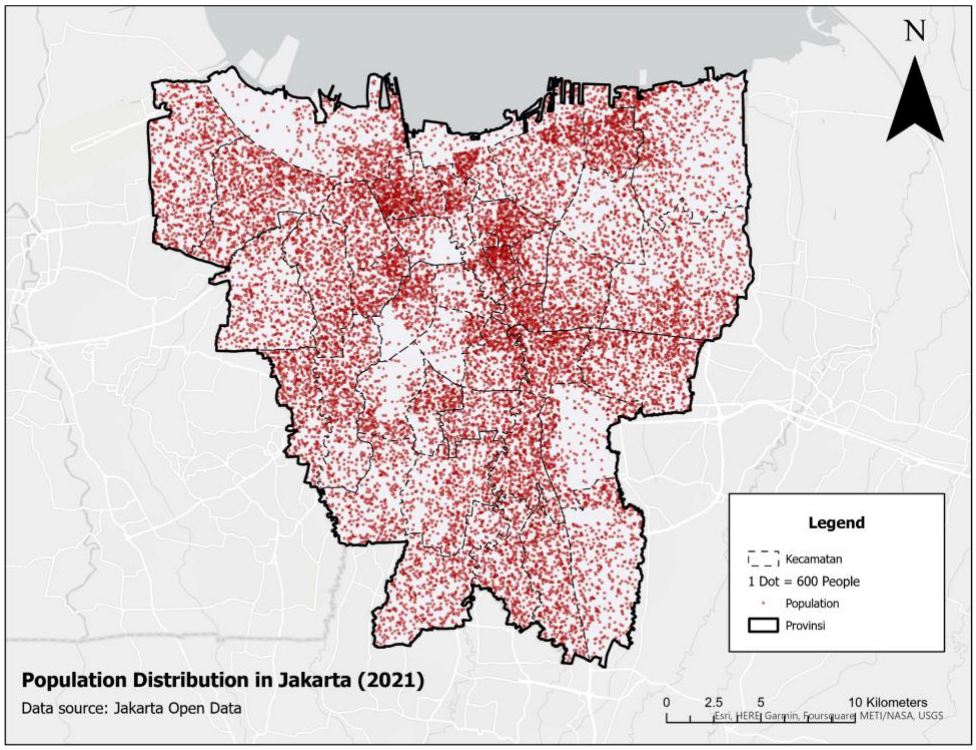
Map Appendix



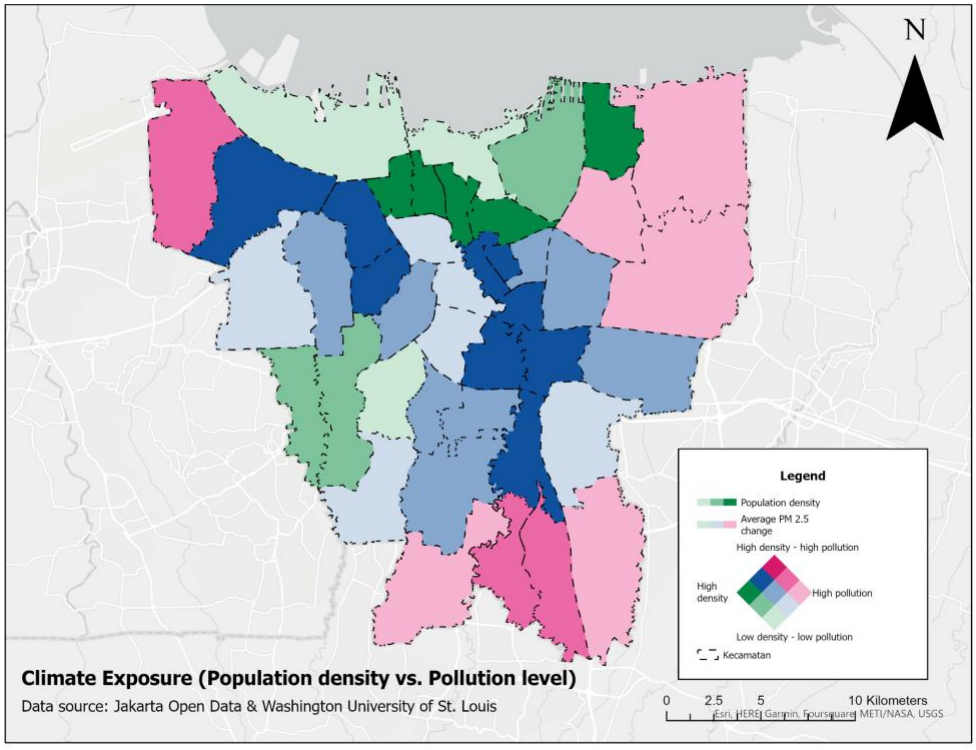
Map 1 Average PM 2.5 level in Jakarta in 2002 (left) and 2022 (right)



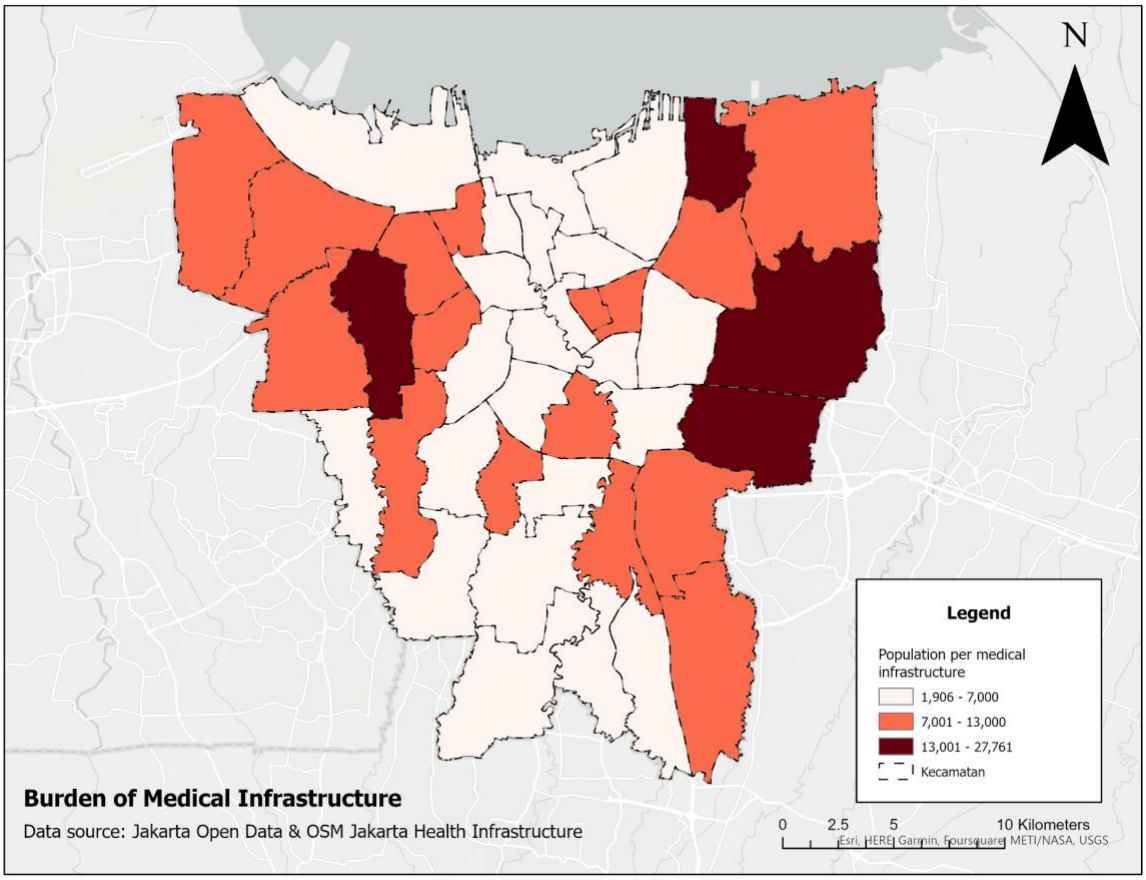
Map 2 Average Change in PM 2.5 level between 2002 and 2022 period



Map 3 Dot density map of Jakarta showing population distribution in 2021



Map 4 Climate exposure and sensitivity across Kecamatan in Jakarta, showing the interaction between population density and pollution



Map 5 Burden ratio of medical structure in Jakarta