VULNERABILITY MAP FOR RESPONSE TO THE COVID-19 EPIDEMIC:
A CASE STUDY ON INDONESIA

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ABSTRACT

The COVID-19 pandemic has emerged as a threat to global health security. This paper uses geospatial analyses to create a COVID Vulnerability Mapping Dashboard that examines and displays social vulnerability indices at the national and subnational levels in Indonesia. The dashboard answers three main questions:

1. Where are the vulnerable populations?
2. What is the capacity of local health systems? and
3. What is the local trend in COVID cases?

The dashboard prototype presented herein was developed and used to direct attention to geographic areas where risks are expected to be greatest.
INTRODUCTION

The COVID-19 (hereafter COVID) pandemic has emerged as a threat to global health security. Given the enormous strain that COVID puts on health care resources, health care systems around the world have been insufficient for responding to this unprecedented shock. The ability to meet care demands requires identifying the most vulnerable populations and areas with severe resource deficits to ensure that preparedness and response efforts make the most effective and efficient use of limited resources. To achieve this objective, this study combines existing social-vulnerability and geospatial information to build a dashboard that allows its users to answer the following questions: 1) Where are the vulnerable populations? 2) What is the capacity of local health systems? and 3) What is the local trend in COVID cases?

This study looks at the case of Indonesia and uses a social vulnerability indexing (SVI) framework to identify which of its communities may require special attention as COVID rages on. SVI measures community resilience in the face of external stressors such as disasters (natural or human caused) and disease outbreaks (Cutter, Boruff et al. 2003). The resilience of a community can be affected by demographic factors (such as age) and socioeconomic factors (such as neighborhood and income) (Juntunen 2005, Flanagan, Gregory et al. 2011). The SVI framework shapes the construction of COVID vulnerability measurements from existing knowledge about COVID contraction and transmission to identify which Indonesians have the highest COVID exposure, the greatest likelihood of contracting it, and the weakest capacity to respond to and recover from it (Surgo Foundation 2021).

In a standard toolkit for communicating health risks to society, geospatial data can be used to describe the potential for harm from a disease outbreak at the local, regional, and national scales and synthesize different drivers of vulnerability, including socioeconomic, demographic, biological, and governance factors. In practice, these data and analytics can facilitate timely response strategies during an outbreak. Geospatial data and analysis have been widely used to develop SVI for geographical targeting in welfare programs (Vicente-Serrano, Beguería et al. 2012, Robin, Khan et al. 2019) and infectious disease control (Le Comber, Rossmo et al. 2011, Fornace, Drakeley et al. 2014), but SVI has been recently employed as a response to the COVID crisis in several countries such as Germany (Scarpone, Brinkmann et al. 2020), India (Saran 2020), and the United States (Jella, Acuña et al. 2020, Sun, Matthews et al. 2020, Zhang and Schwartz 2020).

In this case study, geospatial analyses were used to create a COVID Vulnerability Mapping Dashboard that examines and displays social vulnerability indices at the national and subnational levels in Indonesia. The dashboard prototype presented herein was developed and used to direct attention to geographic areas where risks are expected to be greatest and may require interventions.

METHODOLOGY

The COVID vulnerability mapping dashboard integrates compatible data from a variety of sources, and the data are used to analyze information related to COVID and vulnerable populations using three steps: identifying vulnerable population, mapping the capacity of health care facilities, and incorporating current COVID data in the framework to assess regional situations.

In the COVID vulnerability dashboard, age is the main biological factor included in the analysis, given the age curve seen in cases earlier in the pandemic (Chen, Klein et al. 2021). Also, environmental factors include the available water, sanitation, and hygiene (WASH) amenities
affecting a community’s ability to comply with handwashing and social distancing guidelines as well as population density, particularly in urban areas (Donde, Atoni et al. 2021).

The second step involved mapping the capacity of health care facilities, including data on nurses per 1,000 population, hospital beds per 1,000 population, and doctors per 1,000 population (Ghisolfi, Almås et al. 2020). These data were obtained directly from Indonesia Health Profile.

The third step was adding current COVID case and mortality data to the framework to provide insight into the current situation in a given region. Both descriptive and dynamic data were incorporated into the framework to guide the construction of the COVID Vulnerability Mapping Dashboard. Table 1 summarizes the data, variables, and data sources used to construct vulnerability indices for the Indonesia study.

### Table 1 Data and Variables

#### WHERE ARE THE VULNERABLE POPULATIONS?

<table>
<thead>
<tr>
<th>Variable description</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population older than 55</td>
<td>Percentage population aged 55+</td>
</tr>
<tr>
<td>Open defecation</td>
<td>Percentage of households with open defecation</td>
</tr>
<tr>
<td>Limited sanitation services</td>
<td>Percentage of households with improved sanitation</td>
</tr>
<tr>
<td>Unprotected water</td>
<td>Percentage of households using an improved water source</td>
</tr>
<tr>
<td>Population density</td>
<td>People per square kilometer</td>
</tr>
<tr>
<td>Personal sanitation</td>
<td>People with basic handwashing facilities (soap and water) (% of population)</td>
</tr>
</tbody>
</table>

#### WHAT IS THE CAPACITY OF LOCAL HEALTH SYSTEMS?

<table>
<thead>
<tr>
<th>Variable description</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of hospital beds per 1,000 population</td>
<td>Number of hospital beds per 1,000 people in the district</td>
</tr>
<tr>
<td>Number of physicians per 1,000 population</td>
<td>Number of physicians per 1,000 people in the district</td>
</tr>
<tr>
<td>Number of nurses per 1,000 population</td>
<td>Number of nurses per 1,000 people in the district</td>
</tr>
</tbody>
</table>

#### WHAT IS THE LOCAL TREND IN COVID CASES?

<table>
<thead>
<tr>
<th>Variable description</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of confirmed COVID cases and COVID death count</td>
<td>Government</td>
</tr>
</tbody>
</table>
health system capacity vulnerability, all the risk scores for each variable under that category were summed to get a final vulnerability score. This method is used in the Social Vulnerability Index by the Centers for Disease Control and Prevention (CDC 2021) and COVID Community Vulnerability Index by Surgo Foundation (Surgo Foundation 2021).

RESULTS

WHERE ARE THE VULNERABLE POPULATIONS?

Two distinct maps of vulnerable populations were produced. In Figure 1, Panel A presents the population-at-risk index. The darker the color is, the larger the share of the population at risk. Panel B presents the composite COVID vulnerability index. Both maps highlight the density of risk in Java. While the similarities between these two maps are visually clear, there are some differences in some subareas.

Figure 1  Map of Vulnerable Population

Panel 1A  At-Risk Population

Source: International Health Metrics and Evaluation (IHME), 2021; WorldPop 2021.
Note: World Bank tabulation using WorldPop gridded demographic data and IHME hospitalization rates.

Panel 1B  Composite COVID Vulnerability Index

Note: Combines the vulnerability information (see Figure 1) with Information describing sanitation, and Other Contributing Factors Documented in Table 1.
WHAT IS THE CAPACITY OF LOCAL HEALTH SYSTEMS?

Health system capacity is measured by the average number of beds, average number of nurses, and average number of physicians per 1,000 population. Figure 3 illustrates the health system capacity measured by beds per 1,000 people. The darker the color is, the lower the capacity is.

Figure 2  Health System Capacity (hospital beds)

WHAT IS THE LOCAL TREND IN COVID CASES?

Local COVID trends were measured by the total number of COVID cases and the total number of deaths due to COVID. Figure 4 shows that most COVID cases are in the Dki Jakarta, Jawa Timur, Jawa Barat, and Jawa Tengah provinces.

Figure 3  COVID Cases and Deaths (by province)

We then analyzed social vulnerability index relate to COVID. Figure 5 maps the relationship between COVID cases and vulnerability. In general, where vulnerability is higher, there are more COVID cases and deaths. But some areas with equal or higher COVID vulnerability index figures do not overlap with the circles.
Figure 4  COVID Cases against Vulnerable Population

Panel 4A  COVID Cases against the Population-At-Risk Index

Panel 4B  COVID Cases and the Composite COVID Vulnerability Index

To further examine the relationship between the vulnerability index and COVID cases and deaths, we standardized the total number of COVID cases and COVID deaths and the vulnerability index by mean and standard deviations. Figure 6, normalized COVID cases by province, shows hotspots that have a high vulnerability score and high COVID cases and death, such as Jakarta, Jawa Tengah, and Jawa Timur. The provinces with high vulnerability scores but low COVID cases and deaths, such as Banten and Lampung to a lesser extent, may become hotspots if COVID spreads to these areas.
LIMITATIONS

A few limitations need to be noted. The first is the time lags. Many global data sources, such as Worldpop or Demographic and Health Survey, were collected in previous years. The lack of frequent updates and continuous monitoring can limit accuracy when trying to capture rapidly changing local conditions during disease outbreaks.

The second limitation is the validation of the composite COVID vulnerability index. The vulnerability index was constructed based on current literature on COVID risk factors, and using equal weights. When more COVID case data and retrospective analysis of the trends and community characteristics become available, the vulnerability index can be modified. Importantly, various vulnerability indices can also be constructed to examine the sensitivity of change of variable composition to the final scores.

Last but not the least, some indicators are not available at the regency and city levels. Therefore, we used provincial-level indicators to represent the regencies and cities within those provinces. The variations for those indicators across the regencies/cities within the provinces are not presented.


DISCUSSION AND POLICY IMPLICATIONS

SVI in general has been used by researchers in different contexts to map vulnerabilities, such as in cases of wildfires (Lue and Wilson 2016) natural disasters (Ikeda and Ozanne 2016), and even social pandemics like physical inactivity (An and Xiang 2015, Gay, Robb et al. 2016) and obesity (An and Xiang 2015). SVI is also very useful for health-related vulnerability matrices as used in studies like health and climate change (Balbus, Crimmins et al. 2016) and health inequality mapping (Vick, Thomas-Trudo et al. 2015). The Social Vulnerability Index developed and used by the Centers for Disease Control and Prevention (CDC) uses census data to rank communities based on social factors that affect vulnerability to identify and map communities with the most social vulnerability (Flanagan, Gregory et al. 2011, Wolkin, Patterson et al. 2015).

Similarly, the dashboard in this case study synthesizes spatial information to inform policy makers responsible for COVID-related decisions in the allocation of scarce resources in the fight against COVID. This is achieved by assessing and monitoring the spatial and temporal distribution of risk factors of a COVID outbreak to a given country along biological, behavioral, and environmental lines. The analysis illustrates the potential use of such vulnerability maps for identifying the areas with a higher risk of COVID transmission and COVID impacts, such as mortality rate due to higher proportions of elderly people or insufficient health system capacity. Several COVID vulnerability dashboards have been published elsewhere with global and country-specific information (Marvel, House et al. 2021, UNFPA 2021). While each dashboard has its own features, the objectives are similar: use geospatial and other tools to identify local areas with more vulnerability to the pandemic by combining baseline and dynamic data.

The dashboard in this case study can be further strengthened by incorporating mobility data. Human travel can be a major determinant of the spatial spread of infectious diseases (Wesolowski, Buckee et al. 2016) How, when, and where people move can reveal disease spread and new hotspots (Moss, Naghizade et al. 2019). Mobility data derived from mobile phones is a major source of analysis for tracking human travel, so mobility analysis is an important tool in infectious disease management that has been shown to be a better determinant of disease spread than regular surveys or questions asked in doctors’ offices (Wesolowski, Stresman et al. 2014). As COVID cases continue to rise, several studies are being done to see the effects of mobility on its spread. Studies have been able to prove a link between mobility and COVID transmission rates to enforce the importance of social distancing (Badr, Du et al. 2020, Jia, Lu et al. 2020, Kishore, Kiang et al. 2020).

The dashboard can also be further strengthened by incorporating interventions that have been implemented locally. For example, one of the major policies instituted by governments to curb the spread of COVID has been lockdowns and other movement-restricting nonpharmaceutical interventions. Movement restrictions do not and should not uniformly apply to all communities. Closely tracking and monitoring the implementation of nonpharmaceutical interventions with such vulnerability index and COVID cases maps can help in analyzing the potential impacts of these policies so that only the most effective ones are employed (Buckee, Balsari et al. 2020).

Finally, as more data become available on new COVID mutations (Grubaugh, Hanage et al. 2020), mutation spread, and vaccinated populations, such dashboards can also be used to map the interplay of these factors to provide policy and decision makers policy and decision makers with a more comprehensive picture.
CONCLUSION

The vulnerability map of COVID responses illustrates the variations in vulnerability across Indonesia. This paper illustrates how such tools assist with continuous monitoring of vulnerabilities to help guide limited resource allocation in both planning and implementing COVID-related interventions.
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