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Spatial analysis of the association with composite disadvantage indices and COVID-19 incidence

코로나19 발생률과 복합 취약 지수들 간의 공간 분석

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김 보 은

Spatial analysis of the association with composite disadvantage indices and COVID-19 incidence

지도 교수 황 승 식

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김 보 은

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위 원 장 조성일 (인)

부위원장 이우주 (인)

위 원 황승식 (인)

Abstract

Background: Although the state of emergency was lifted in May 2023, COVID-19 continues to cause numerous cases and deaths. This study aimed to identify vulnerable communities and factors contributing to the COVID-19 outbreak utilizing the composite disadvantage indices.

Methods: Data on COVID-19 cases in each municipality were analyzed in relation to composite disadvantage indices. Spatial autocorrelation was evaluated using Moran's I, and the relationship between composite disadvantage index values and the number of COVID-19 cases over time was analyzed through spatial regression using OLS, SLM, and SEM models in Geoda.

Results: COVID-19 cases and composite disadvantage indices exhibited positive spatial autocorrelation. CCVI values indicated a positive relationship with COVID-19 cases over time. SLM model consistently showed higher coefficients and lower AIC values across all years (2020: 0.597, -1680.99; 2021: 0.723, -2180.74; 2022.1-6: 0.143, -2516.87).

Conclusion: The composite disadvantage indices of 249 municipalities were identified, and hotspots were founded by spatial analysis. There was a positive correlation between CCVI and COVID-19 incidence over time. Thus, it is necessary to prepare countermeasures that consider vulnerability factors by city and district to respond to infectious diseases such as COVID-19.

Keyword : COVID-19, Incidence, Spatial Analysis, Composite disadvantage index
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Chapter 1. Introduction

1.1. Study Background

On January 30, 2020, The World Health Organization (WHO) announced that it was lifting its Pandemic Health Emergency Internationally Concerning Coronavirus (PHEIC) (WHO, May 5, 2023). South Korea lifted social distancing measures on May 11, 2023, and downgraded its COVID-19 pandemic alert from severe to alert. COVID-19 has caused many infections and deaths worldwide and has also had a significant socioeconomic impact. Tortolero et al. (2022) explored the association between Social Vulnerability Index (SVI) values and COVID-19 incidence in Texas using incident risk ratios and reported weak associations with ethnicity and language (1.107 (95% confidence interval (CI): 1.098, 1.115)) and socioeconomic factors (1.090 (95% CI: 1.083, 1.098)). Many studies have been conducted on social vulnerability, and several suggested that it may vary by region in many countries (Lin et al., 2021; Macharia et al., 2020; Kim, 2022).

According to the United States Centers for Disease Control and Prevention (CDC), disasters occur when an adverse environment meets vulnerability, and the United Nations Disaster Reduction Agency and much of the literature suggest that risk increases with increased vulnerability to hazardous conditions. A systematic literature review by Aliabadi et al. (2022) found that the impact of COVID-19 varied according to the presence of public health infrastructure and that understanding local vulnerabilities was a priority.

To identify the impact of socioeconomic vulnerability on health in Korea, Kim et al. (2013) developed 88 indicators in three factors: socio-structural factors, mediating factors, and health outcomes. Choi et al. (2019) modified these indicators to construct nine natural unit socioeconomic factors to confirm the increasing

polarization. The indicators are often used in the United Kingdom, the United States, and Canada, but their use in policymaking has been insufficient in Korea (Choi et al., 2019). This regional deprivation index has been used in studies, such as survival rates by major cancer types in cancer screening projects (Kang et al., 2022) and effects on subjective health levels (Park et al., 2016).

As health inequalities before and after COVID-19 have been reported, it is necessary to study the association between health inequalities and COVID-19 impact considering regional vulnerabilities.

1.2. Literature Review

The Pandemic Vulnerability Index (PVI) was developed in the United States by modifying the Social Vulnerability Index (SVI) of the CDC, and the COVID-19 Community Vulnerability Index (CCVI) was developed by Surgo Ventures[①] to identify the vulnerability of each county due to COVID-19 along with the outbreak status. Various other indices have been developed, including the Social Vulnerability Index (SoVI) proposed by the South Carolina Research Institute to identify the impact of flooding.

Studies have been conducted on the relationship between indicator values and COVID-19 health outcomes. Tipirneni et al. (2022) compared four social vulnerability indices, the CDC Social Vulnerability Index (CDC-SVI), the CCVI, the Area Deprivation Index (ADI), and the Minority Health Social Vulnerability Index, with COVID-19 incidence and mortality and found that incidence was correlated with all index values, but mortality was only correlated with ADI values. Wolkin et al. (2022) explored the validity of the indicators by comparing the SVI, CCVI, and PVI, which are used by the CDC, and found a significant association

① Surgo Ventures was established in December 2020 by a team of founders, including Co-Founder and CEO Sema Sgaier. It is a nonprofit organization headquartered in Washington, DC, with a hub in the UK, dedicated to addressing health and social challenges through innovative, data-driven approaches.

between COVID-19 incidence and mortality using the SVI indicator in Florida but suggested that further research on individual factors is needed. Baker et al. (2022) and Fraser (2020) found that social ties and mobility in Japan were useful tools for predicting and controlling the coronavirus pandemic using the Japanese Social Capital and Social Vulnerability Indices. Acharya and Porwal (2020) developed a social vulnerability index in Japan using the CDC-SVI and found a high vulnerability in many regions except for the northeast. Kim (2020) compared SVI values in 2015 and 2019 and COVID-19 incidence in 2020 in the Seoul metropolitan area and found a positive correlation between the increases in index values and incidence.

Several studies conducted in South Korea have explored the association between vulnerability index scores, socioeconomic factors, and the incidence or spread of COVID-19, aiming to understand the relationship between these factors and COVID-19. In a study by Kim (2020), the association between SVI and the incidence of COVID-19 in the Seoul metropolitan area was investigated. The results revealed a significant positive correlation between the difference in SVI values from 2015 to 2019 and the incidence of COVID-19. Kim (2022) analyzed demographic and socioeconomic factors, such as age, gender, regional income levels, and excess mortality, to explain the negative excess mortality in 2020. Kim (2021) conducted a spatial regression analysis using Moran's I between coronavirus incidence and individual socioeconomic factors (number of medical personnel, density, movement, economic activity, and college degree or higher) in Seoul and found that none of the individual socioeconomic factors were significant.

Some studies have explored spatial factors and the spatial correlates of coronavirus incidence. Jo et al. (2021) analyzed the correlation between national coronavirus incidence, density, and connectivity and found that density and geographic connectivity were important factors in coronavirus outbreaks. Lym et al. (2022)

analyzed the correlation between the size and incidence of municipalities in the metropolitan area by period using Bayesian spatiotemporal models. Kang (2022) conducted a spatiotemporal analysis of COVID-19 outbreak changes from February 18, 2020, to May 21, 2021, divided into five periods, using scan statistics and Moran's I. In particular, the spatial correlation between the incidence rate and the metropolitan area was confirmed. Bae, Choi, and Oh (2022) analyzed the relationship between the incidence of COVID-19 and vulnerable facilities, vulnerable groups, and social vulnerability conditions in 229 cities and counties until January 6, 2022. They found that social vulnerability conditions, representing population density and mobile populations, had the highest impact on the incidence of COVID-19 (standardized coefficient ß 0.85, P < .001). Lee (2023) calculated an infectious disease vulnerability index for Korea and conducted a regression analysis between the number of reports of grade 1 communicable disease for three years and factors reflecting socioeconomic factors, household composition and disability, housing and transportation, and economic activity. The study found that urban factors, such as gross regional product, public transport usage, and population density, were significantly correlated with the number of reports.

Previous studies analyzed the correlation between the incidence of COVID-19, regional vulnerability indicators, and infection vulnerability factors, and identified the relevance of the ADI and other factors in Korea, such as population density, mobile population, public transport usage, and gross regional product. However, previous studies on the correlation between the social vulnerability index (SVI) and COVID-19 incidence had limitations, focusing on metropolitan areas and excluding the analysis of the Omicron period. The utilization of spatial analysis to explore this relationship was also limited. Therefore, it is necessary to explore the relationship between vulnerability and incidence in each region of the country through spatial analysis techniques.

The objective of this study was 1) to investigate whether there

are differences in composite disadvantage index values in municipals, 2) to determine whether composite disadvantage index values are spatially autocorrelated, and 3) to elucidate the relationship between composite disadvantage index values and COVID-19 incidence using statistical analysis models.

Chapter 2. Method

2.1. Study area

This study covered 250 municipalities, including autonomous regions. However, 249 municipalities were selected as the study area, excluding Ongjin-gun, Incheon, which had no confirmed cases. Administrative units in South Korea are divided into basic local governments and metropolitan local governments, and subordinate units are Si-Gun-Gu, which are basic local governments. While towns, counties, and districts are the lowest administrative units in which local governments conduct local affairs, such as administrative management and the promotion of resident welfare, to compare regional differences in characteristics, we used regional cities and district divisions, which are subordinate organizations of basic local governments.

2.2. Data selection and preparation

Three widely recognized composite vulnerability indices, CDC-SVI, ADI, and CCVI, were selected as independent variables in this study. These indices have been previously utilized in research and are commonly employed by administrative agencies. The characteristics of each index are shown in Table 1.

Table1 Characteristic of three composite disadvantage indices

Characteristic	Social Vulnerability Index (CDC-SVI)	Korea Area Deprivation Index (ADI)	Covid19 Community Vulnerability Index (CCVI)
Year developed	2011	2013	March 2020
Latest Update	2022	2017	December 2020
Purpose	To identify communities that need support from natural disasters or human-made hazardous events	To identify the level of regional gap and examine which communities are vulnerable	To assess which communities may be less resilient
Geographic unit reported	County	Municipal	State, county/ census tract
No. of variables	16	9	40
Index-defined construct domains	1) Socioeconomic status 2) Household characteristics 3) Race and ethnic/minority status 4) Housing type and transportation	Index reflecting Population, socioeconomic status of a region	1) Socioeconomic status 2) Minority status and language 3) Housing type, transportation, household, composition, and disability 4) Epidemiological factors 5) Healthcare system factors 6) High-risk environments 7) Population density
Calculation method	Percentile ranking range: 0 to 1	Z-score Range: -1 to 1	Percentile ranking/ range: 0 to 1
Developer	Centers for Disease Control and Prevention, Agency for Toxic Substances and Disease Registry, Geospatial Research Analysis, and Services Program	Choi et al. developed the Korean Area Deprivation Index made by Kim Dong-jin et al	Surgo Ventures

The CDC-SVI was first developed in 2011 in response to Hurricane Katrina, which struck the United States in 2005 and

devastated New Orleans and was designed to identify vulnerable populations that are more likely to be affected than the general population, as well as for disaster response. (CDC/ATSDR, 2022) The CDC-SVI consists of four broad categories and 16 sub-categories (Appendix 1), and each sub-variable is summed according to the broad category, added together to obtain a total, and calculated as a percentile rank value at each step. It ranges from 0 to 1, with higher scores indicating more vulnerable areas.

In order to reflect the original indicator, we changed "Single-Parent Households" to single children, rather than children under 18 years of age, and "Mobile Homes" to "Non-residential buildings," which are living quarters other than offices. "Racial & Ethnic Minority status" is a registered foreigner with a nationality other than OECD[②] countries, which has been modified to suit the domestic situation. "No Health Insurance" was omitted because Korea has a mandatory national health insurance policy, and "English Language Proficiency" was deleted because we were unable to collect data by city and district. The following are the revised indicators.

- Socioeconomic status: Below 150% poverty, Unemployed, Income per capita, No high school diploma
- Household characteristics: Elder, Younger, Population with a disability, Single parents household
- Race and Ethnic/Minority status: Foreigners
- Housing Type and transportation: Multi-unit structures, Non-residential buildings, Crowding, No vehicle, Group quarters

The Area Deprivation Index (ADI) was developed by Kim, Dong-jin, et al. in 2010 (KorDep_2010), which extracts components related to demographic and socio-economic factors,

② The Organization for Economic Co-operation and Development (OECD) is an intergovernmental organization with 38 Member countries, founded in 1961 to stimulate economic progress and world trade.

and is composed of education level, unemployment, social class, household type, marital status, living environment (housing type, living conditions, etc.), car ownership, etc. as deprivation index components based on the 2015 Population and Housing Census, and is calculated by Jihee Choi et al. (2019) by selecting components and standardizing them (z-score) and summing them. In this study, the z-score was changed to a percentile rank for comparison with other indicators.

- Poor households
- Unemployed
- No high school diploma
- Elder
- Divorced or separated
- Single household
- Female head of household
- Living without apartment
- Poor housing condition

The CCVI was developed by the nonprofit Surgo Ventures in the wake of COVID-19 and is an indicator for identifying which areas of the world are more vulnerable to COVID-19 in terms of socioeconomic and health outcomes, with seven broad categories and 40 subcomponents. (Appendix 2) Each subfactor is assigned a percentile rank and then summed across categories to produce a total overall value. It has a value between 0 and 1, and the closer it is to 1, the more vulnerable the area. (Surgo Ventures, 2020)

The original indicators were followed, but four indicators were omitted because they did not fit the Korean situation or because there was no data source for each city and district: "Percent of population uninsured", "Speaks English "Less than Wel6l", "Number of Epidemiologist", and "Prisoners per 100,000", and the modified indicators from the CDC-SVI were reflected, while some indicators were changed by referring to the indicators used in Lee (2023),

who studied the vulnerability of Korean infectious diseases. "Cardiovascular conditions" was changed to "having been diagnosed with hypertension over the age of 30," "recognition of early symptoms of "stroke," [③] "myocardial infarction," [④] and "hospitalization for angina," respectively. "Respiratory conditions" was changed to the number of hospitalizations for chronic obstructive pulmonary disease. Cancer incidence rates were defined as age-standardized incidence rates per 100,000 people for 24 cancers (C00-C96) [⑤] . "Total Public Health Emergency Preparedness (PHEP) Funding Per Capita" was replaced by local government financial independence. We switched to fiscal self-sufficiency, which has been used in several studies as an alternative indicator of local government preparedness due to large disparities in funding rates across regions and large differences in utilization (Lee, 2023). "Health Labs per 100,000" was changed to the number of clinical laboratories per 100,000 people by region, "Long-term care residents per 100,000" was replaced with the number of people living in welfare facilities, and "Prisons population per 100,000" was replaced with the gross floor area (㎡) of correctional facilities by region.

Avoidable hospitalization rates refer to the percentage of hospitalizations that could have been prevented through appropriate

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③ Percentage of people who answered all the questions correctly about early symptoms of stroke (hemorrhagic stroke) (sudden loss of strength in one face, arm, or leg; sudden slurred speech; inability to understand what others are saying; sudden loss of sight in one eye or half of the vision; seeing objects in double; sudden dizziness or difficulty centring oneself; sudden severe headache unlike any you have ever had before), corrected for the standard population (2005 Census, National Statistics Office).

④ Percentage of people who answered all of the questions about early symptoms of myocardial infarction (suddenly have pain or tightness in the jaw, neck, or back; suddenly feel weak, dizzy, or break out in a cold sweat; suddenly have pain, pressure, or squeezing sensation in the chest; suddenly have pain or discomfort in the arms or shoulders; suddenly feel short of breath) by city, county, and district, corrected for the standard population (2005 Autumn Population Survey, National Statistical Office)

⑤ Lips, mouth and pharynx (C00-14), esophagus (C15), stomach (C16), large intestine (C18-20), liver (C22), gallbladder and other biliary tract (C23-24), pancreas (C25), larynx (C32), lungs (C33-34), breast (C50), cervix (C53), uterus (C54), ovaries (C56), prostate (C61), testicle (C62), kidney (C64), bladder (C67), brain and central nervous system (C70-72), thyroid (C73), Hodgkin lymphoma (C81), non-Hodgkin lymphoma (C82-86, C96), multiple myeloma (C90), leukemia (C91-95), other cancers (Re. C00-96), and other cancers (Re. C00-96) Corrected to the standardized population of the 2020 National Population Register.

primary care or outpatient treatment. These rates are calculated for specific conditions that are considered preventable with timely and effective healthcare interventions. The conditions in this study included in the calculation of avoidable hospitalization rates are hypertension, congestive heart failure, angina pectoris, diabetes acute complications, diabetes mellitus, adult asthma, COPD (Chronic Obstructive Pulmonary Disease), bacterial pneumonia, urinary tract infection, appendicitis perforation rate, pediatric asthma, pediatric gastroenteritis, pediatric bacterial pneumonia, pediatric urinary tract infection, and pediatric perforated appendicitis. These rates serve as indicators of the effectiveness of primary care services and the accessibility of healthcare interventions in preventing the progression of these conditions to a point where hospitalization becomes necessary.. "Percentage of population employed in high-risk industries" was converted by Choi (2020) to skilled workers in agriculture, forestry, and fisheries, skilled workers and related trades, workers in apparatus, machine operation and assembly, and manual laborers with a value of zero for jobs that can be worked from home. The revised indicators are as follows.

- Socioeconomic status: Below 150% poverty, Unemployed, Income per capita, No high school diploma
- Race and Ethnic/Minority status: Foreigner
- Housing type, transportation, household composition and disability: Multi-unit structures, Crowding, No vehicle, Group quarters, Younger, Single parents household, Access to Indoor Plumbing, Non-residential buildings, Population with a disability
- Epidemiological Factors: Cardiovascular conditions, Respiratory conditions, Immuno-compromised, Obesity, Diabetes, Elder
- Healthcare System Factors: Health system capacity, Health system strength, Healthcare accessibility, Health system preparedness

- High risk Environments: Percentage of population working or living in environments with high infection risk
- Population density: Population density

The dependent variable is the cumulative number of confirmed cases per 100,000 by section by city and district as of June 27, 2022 including the number of new infectious disease syndromes in 2020 and 2021 and the epidemic according to the omicron variant that showed the largest epidemic curve nationwide(Figure 1).

The amended factors of composite vulnerability indices SVI, ADI, and CCVI used in this study were compared (Table 2). The SVI has 14 factors, the ADI has 9 factors, and the CCVI has 37 factors, including subfactors. Detailed reference sources are listed in Appendix 4.

Figure1 Daily new confirmed covid19 cases per 1 million

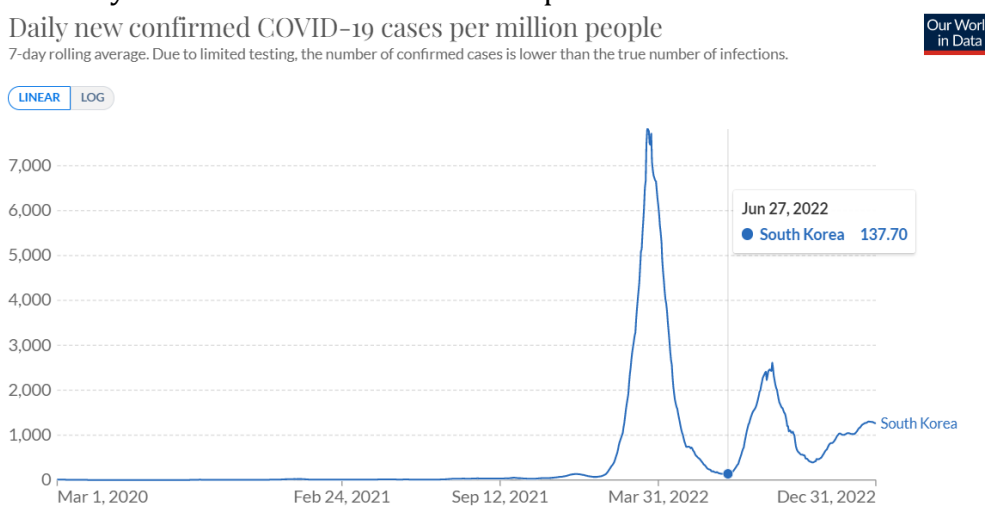


Table2 Description of revised SVI, ADI, and CCVI

Domain	Variable	Description	SVI	ADI	CCVI	Year Source
Socioeconomic status	Below Poverty	% of population belonging to household with incomes below 50% of the median monthly household income*	O		O	2019 Community Health Survey
	Income per capita	Average Gross Regional Domestic Product per capita	O		O	2019 Gross Regional Domestic Product Statistics
	Poor households	% of all household members in households where the head is engaged in agriculture/fishery as a self-employed worker, a simple laborer, or an employee among all members are aged 15-64 years		O		2020 Population and Housing Census
	Unemployed	% of Unemployed population aged ≥ 16 years	O	O	O	
	No high school Diploma	% of population with no high school diploma aged ≥ 25 years	O		O	
		% of population with less than a high school diploma aged between 15 and 64 years		O		
Population & Household Characteristics	Younger	% of population aged ≤ 17 years	O		O	
	Single-Parent Households	% of single-parent household with no married children aged <18 years	O		O	
	Divorced or separated	% of divorced or separated population aged ≥ 15 years		O		
	Single households	% of Single household among the total households		O		

	Female head of household	% of female head of household among the total households		O		
	Population with disability	% of population not in an institution who are 5 years of age and older with a disability	O		O	
Minority	Foreigner	% of foreigner not Korean nationality or not from OECD among the total registered foreigners	O		O	2019 Foreigner Residents Statistics
Housing & Environment	Non-residential buildings	% of households living in inadequate housing conditions; Hotels, inns, and other lodging facilities, Dormitories and special communal facilities, Makeshift structures such as shacks and plastic houses, Other (temporary residences such as sleeping quarters in businesses or makeshift structures on construction sites)	O		O	2020 Population and Housing Census
	Multi unit-structure	% of households living in single-family houses with 10 or more households or in multi-family houses	O		O	
	Crowding	% of occupied housing units (i.e., households) with more than one person per room	O		O	
	Group Quarters	% of households that unrelated households of 6 or more people or Institutional households *	O		O	
	Living without apartment	% of households not living in apartments		O		
	Poor housing condition	% of households without a modern-style separate kitchen, a private bathroom, a private bath, an independent water supply, or a water heating system		O		
	No indoor Plumber	Percentage of households without access to indoor plumbing			O	
	No Vehicle	% of households with no vehicle	O		O	

Epidemiological Factor	Elder	% of older adults aged ≥ 65 years	O	O	O	
	Cardiovascular Conditions	% of adults diagnosed with hypertension			O	2019 Community Health Survey
		% of adults recognized with early symptom of myocardial infarction			O	
		% of adults recognized with early symptom of stroke			O	
		% of adults hospitalized with Angina			O	2019 Health map, National medical center
	Respiratory Conditions	% of adults hospitalized with chronic obstructive pulmonary disease			O	
		% of current smokers ("smoking every day" or "smoking sometimes") among individuals who have smoked 5 packs (100 cigarettes) or more in their lifetime (up to now) adjusted using standard population (2005 estimated population, Statistics Korea)			O	2019 Community Health Survey
	Immuno-compromised	Age-standardized cancer(C00-C96) incidence per 100,000 persons from 2013 to 2018			O	2018 Cancer registration
		% of population living with an HIV diagnosis per 100,000 people			O	2015 National Health Care Survey
	Obesity	% of population who reports a body mass index (BMI) greater than or equal to 25 kg/m2 adjusted using standard population (2005 estimated population, Statistics Korea)			O	2019 Community Health Survey
	Diabetes	% of population with diabetes diagnosed by doctor≥ 30 years			O	
Healthcare system Factor	Health System Capacity	Intensive Care Unit (ICU) Beds per 100,000			O	2019 Regional Healthcare

		Hospital Beds per 100,000			O	utilization statistics
	Health System Strength	Preventable hospitalization rates by healthcare provider location			O	2019 National Health Care Survey
		Health spending per capita			O	2019 Regional Healthcare utilization statistics
		Aggregate cost of medical care			O	
	Healthcare Accessibility	General practitioners per 100,000 population			O	
	Health System Preparedness	% of Financial Independence of Local Government			O	2019 Health map, National medical center
		Clinical examination per 100,000 population			O	2019 National health Insurance static
		Emergency beds per 100,000 population			O	
High Risk Environment	environments with high infection risk	Long-term care residents per 100,000 population			O	2019 Welfare, living by facility type,
		Percentage of population employed in high-risk industry			O	2019 Community Health Survey
Population Density	Population Density	Estimated total number of people per unit area (sq. kilometers)			O	2019 Korea city statistics

2.3. Statistical Analysis

To check whether each metric is spatially autocorrelated, we will use Moran's I. Moran's I is a measure of autocorrelation, which has a value between −1 and 1, with a higher positive value indicating higher spatial autocorrelation. The formula for Moran's I is as follows, and for spatial weighting, we will use the Queen method, which weighs all faces and lines, including corners.

$$I = \frac{n\sum_i\sum_j W_{ij}(Z_i - \bar{Z})(Z_j - \bar{Z})}{(\sum_i\sum_j W_{ij})\sum_k (Z_k - \bar{Z})^2}$$

N: the number of spatial units indexed by i and j
Z: the variable of interest
bar(z): mean
w {ij} spatial weight

To explore the correlation between the COVID−19 incidence and each indicator, we first examine the residuals using an Ordinary Least Square (OLS) model, which typically checks for correlation between the dependent and independent variables (Anselin and Arribas−Bel, 2013).

$$y_i = \beta_0 + x_i\beta + \epsilon_i$$

i denotes a municipality, yi is the COVID−19 incidence, xi is the value of each indicator, β is the regression coefficient, and εi is the Random error term. An important assumption of OLS is that observations are independent across study areas and are not correlated with chance errors. At the municipal level, the OLS assumption is to maintain spatial independence, which is not affected by space, but it is difficult to maintain spatial independence

because the incidence of COVID-19 is affected by close spatial proximity. Therefore, after checking the spatial dependence through the residuals, this study applies two spatial regression methods: Spatial Error model and Spatial Lag model. Spatial Error model is applied to the residuals obtained from OLS model, and SLM model is calculated by controlling the dependent variable.

The formula for Spatial Error model is as follows. i is a tract, ξi is the error of the spatial element, and λ is the degree of correlation at the tract level.

$$y_i = \beta_0 + x_i\beta + \lambda W_i\xi_{s_i} + \epsilon_i$$

The Spatial Lag model equation is as follows. i is a municipality, p is a spatial autocorrelation parameter, and Wi is a spatial weighting matrix, which is calculated by multiplying neighborhoods into a weighting matrix by assigning a value of 1 to neighborhoods where the outcome variable and explanatory variables are related in i and a value of 0 to non-neighborhoods.

$$y_i = \beta_0 + x_i\beta + pW_iy_i + \epsilon_i$$

To compare the OLS model with the spatial analysis models SEM and SLM, we will apply each metric to the three models and use the Geoda. The Queen method will be used for spatial weighting, and the Akaike Information Criterion (AIC) and R^2 values will be used to explore which model explains the COVID-19 incidence better. To analyze the correlation between subindices and COVID-19 incidence, Spearman correlation analysis was conducted using R.

2.4. Ethical issues

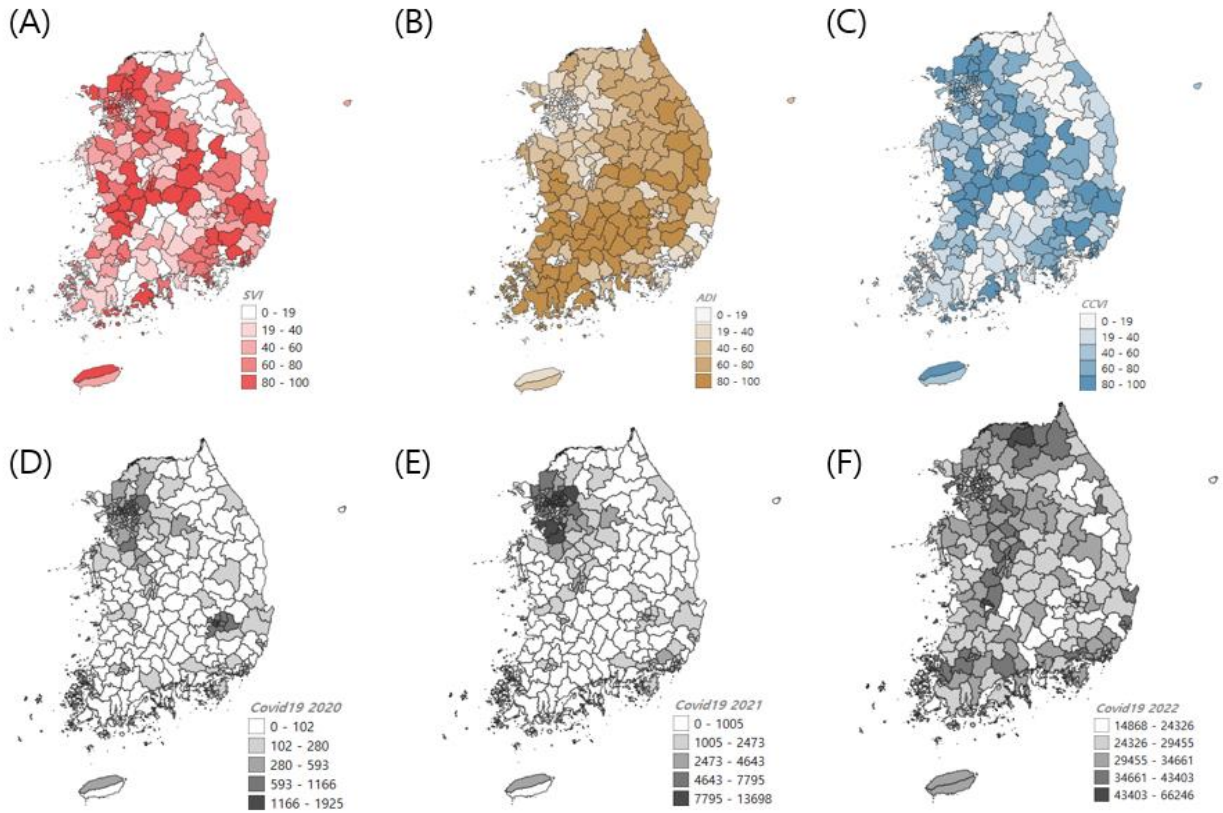
This study was exempted from the Institutional Review Board of Seoul National University as it does not involve human participants and does not collect personally identifiable information.

Chapter 3. Result

3.1. Descriptive Analysis

The SVI was highest in Michuhol-gu, Incheon, followed by Namdong-gu, Incheon (0.995), Gyeongju-si, Gyeongbuk (0.991), Iksan-si, Jeollabuk-do (0.987), and Tongyeong-si, Gyeongnam (0.983) as the top five vulnerable areas. Yeongcheon-si, North Gyeongsang Province (0.9) and Yeongdong-gun, Gyeongnam Province (0.983) were among the top five vulnerable regions. The ADI was highest in Boseong-gun, followed by Uisung-gu, Gyeongbuk 0.995, Yeongdeok-gun, Gyeongbuk 0.991, Goheung-gun, Jeonnam 0.987, and Haenam-gun, Jeonnam 0.983. The CCVI was highest in Michuhol-gu, Incheon, followed by Bupyeong-gu, Incheon (0.995), Saha-gu, Busan (0.991), Namdong-gu, Incheon (0.987), and Bucheon-si, Gyeonggi-do (0.983). In 2020, the Covid19 incidence rate was concentrated in the Seoul metropolitan area and Daegu Gyeongbuk, while the 2021 coronavirus incidence rate increased in the Seoul metropolitan area. In 2020, the number of COVID-19 cases per 100,000 people was high in Seoul, some metropolitan areas, and Daegu, with Songpa-gu, Seoul (1925), Buk-gu, Daegu (1693), Dalseo-gu, Daegu (1599), Gangseo-gu, Seoul (1341), and Bucheon, Gyeonggi (1166). In 2021, COVID-19 cases per 100,000 people were concentrated in Seoul and some metropolitan areas, including Gangnam-gu, Seoul (13698), Songpa-gu, Seoul (13432), Bucheon, Gyeonggi (11253), Yeongdeungpo-gu, Seoul (10764), and Guro-gu (10586). From January 1 to June 27, 2022, the number of COVID-19 cases per 100,000 people increased significantly across the country, with Seoul's Jung-gu (66246), Incheon's Dong-gu (56677), Gangwon's Hwacheon-gun (56071), Jeonju's Deokjin-gu (51817), and Busan's Dong-gu (47875) being the highest. (Figure 2)

Figure2 Map of 3 composite disadvantage indices and Covid-19 incidence rate



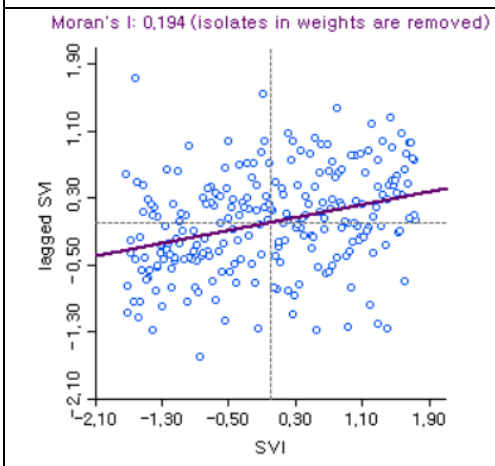
(A) Social Vulnerability Index (SVI), (B) Korea Area Depravation Index (ADI), (C) Covid19 Community Vulnerability Index (CCVI)
(D) Covid19 incidence in 2020, (E) Covid19 incidence in 2021, (F) Covid19 incidence from 1 January to 27 June 2022

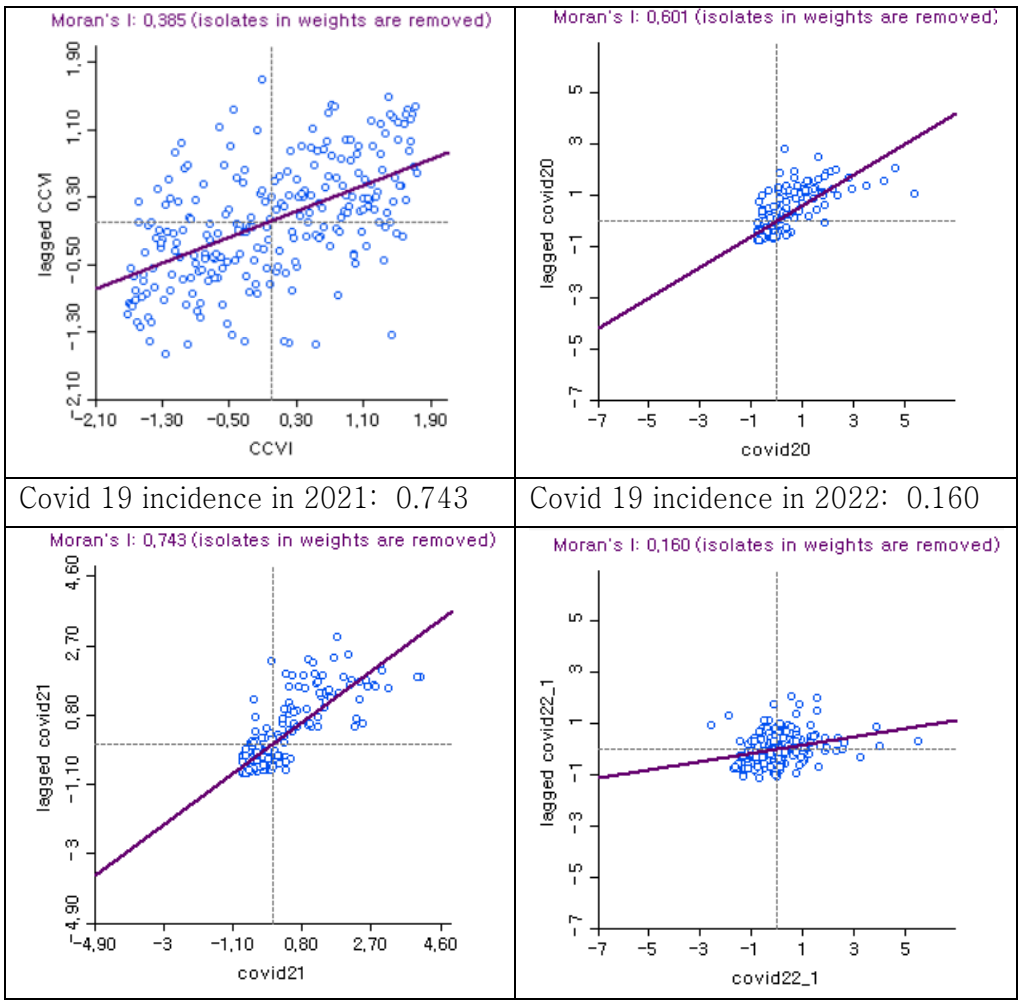
3.2. Spatial Autocorrelation

Eight cities, counties, and districts (Yeongdo-gu, Busan; Ganghwa and Ongjin-gun, Incheon; Wando and Jindo-gun, Jeollanam-do; Ulleung-gun; Geoje, Gyeongnam; and Namhae-gun) were excluded due to lack of neighbors when applying spatial matrix weighting.

The spatial autocorrelation was checked with the Global Moran's I value, which was 0.194 for SVI, 0.385 for CCVI, and 0.703 for ADI, respectively, with ADI showing particularly strong spatial autocorrelation. The Covid19 incidence rate increased to 0.601 in 2020, 0.743 in 2021, and dropped sharply to 0.16 in June 2022. This is likely due to the initial clustering of cases in the Seoul metropolitan area, Daegu, and Gyeongbuk provinces, which expanded nationwide after the omicron mutation.

Figure3 Moran's I for 3 composite disadvantage indices and Covid 19 incidence rate

SVI: 0.194	ADI: 0.703
	
CCVI: 0.385	Covid 19 incidence in 2020: 0.601

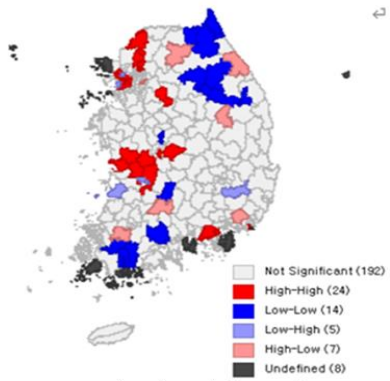


SVI's High-High regions included 24 areas around Seoul (Gangbuk-gu, Dobong-gu, Nowon-gu, Guro-gu), Incheon (Namdong-gu, Bupyeong-gu, Seo-gu), Uijeongbu-si, Bucheon-si, Gwangmyeong-si, Dongducheon-si, Siheung-si, Icheon-si, Yangju-si, Yeoncheon-gun, Busan-si Seo-gu, Daejeon-si Jung-gu, Okcheon-gun, Nonsan-si, Buyeo-gun, Seocheon-gun, Iksan-si, Wanju-gun, and Goseong-gu. In the case of ADI, the Seoul metropolitan area and the Busan area were classified as Low-Low, and 64 areas in Jeolla Province, Chungcheong Province, Gyeongsangbuk-do Province, and Gangwon Province were categorized as High-High region. There were 32 CCVI hotspots, concentrated in the Seoul metropolitan area and Busan. Seoul

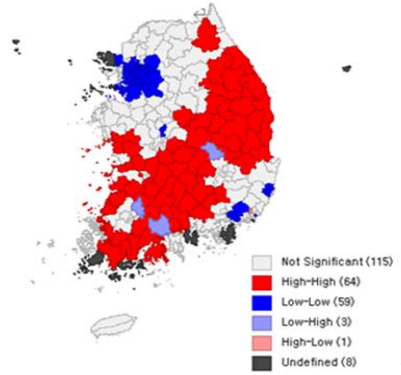
(Jungnang-gu, Seongbuk-gu, Gangbuk-gu, Dobong-gu, Nowon-gu, Yangcheon-gu, Gangseo-gu, Guro-gu, Geumcheon-gu, Yeongdeungpo-gu), Incheon (Namdong-gu, Bupyeong-gu, Gyeyang-gu, Seo-gu), Uijeongbu-si, Gyeonggi, Anyang, Manan-gu, Bucheon, Gwangmyeong, Pyeongtaek, Ansan-si, Danwon-gu, Goyang-si, Deokyang-gu, Siheung-si, Yangju-si, parts of Busan (Seo-gu, Dong-gu, Busanjin-gu, Dongnae-gu, Buk-gu, Yeonje-gu, Suyeong-gu, Sasang-gu) and Yangsan-si, Gyeongnam were designated as hotspots.

In 2020, the vulnerable areas for COVID-19 outbreaks were all areas of Seoul except Dobong-gu, and the Seoul metropolitan area (Namdong-gu, Bupyeong-gu, Gyeyang-gu, Seongnam-gu, Uijeongbu-si, Uijeongbu-si, Anyang-gu, Bucheon-si, Gwangmyeong-si, Deokyang-gu, Goyang-si, Guri-si, Siheung-si, Hanam-si, and Gimpo-si). All of Daegu and Gyeongsan, Gyeongsangbuk-do were classified as hotspots, and 2021 showed a concentration of High-High areas in the Seoul metropolitan area. However, in 2022, 12 areas were identified: Seongdong-gu, Seoul; Jung-gu, Incheon; Jung-gu, Busan; Nam-gu, Gwangju; Anseong-si, Gyeonggi-do; Pocheon, Gyeonggi-do; Chuncheon, Gangwon-do; Cheorwon-gun; Hwacheon-gun; Yang-gu-gun; and Cheongwon-gu, Cheongju-si. (Figure 4)

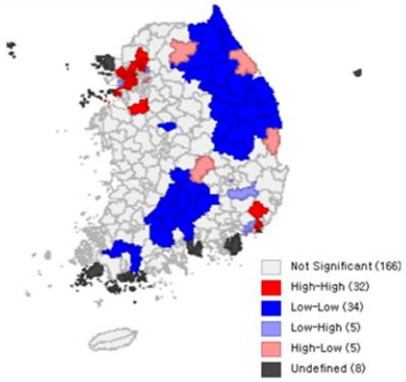
Figure4 Local Moran's I between 3 composite disadvantage indices and covid19 incidence by period



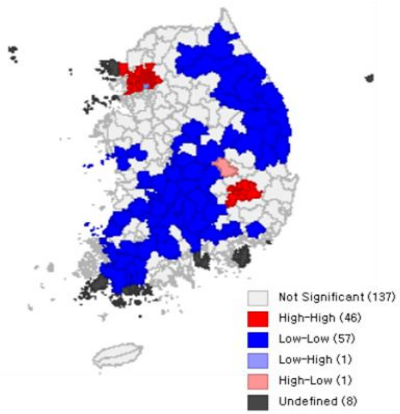
(A) Social Vulnerability Index(SVI)



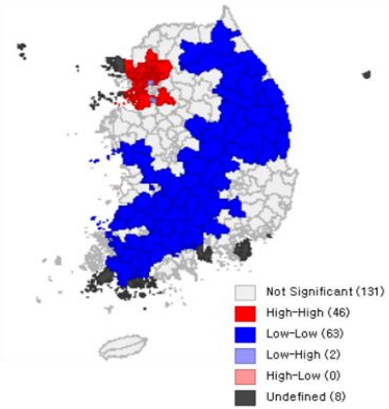
(B) Korea Area Deprivation Index(ADI)



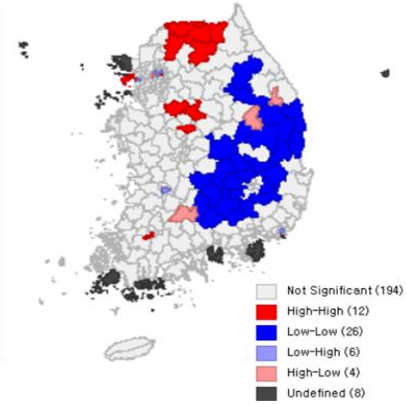
(C) Covid-19 Community Vulnerability Index(CCVI)



(D) Covid19 incidence in 2020



(E) Covid19 incidence in 2021



(F) Covid19 incidence in 2022.1~6

3.3. Spatial regression analysis

The correlation between the composite vulnerability index and the incidence of COVID-19 was analyzed through three regression models (Table 3). The coefficient of determination R2, which is an indicator that the independent variable explains the variation of the dependent variable, was 0.591, 0.723, and 0.143 for SLM compared to OLS and SEM, respectively, showing the highest explanatory power of the model. The AIC value of SLM was the lowest at 3371.98 for COVID-19 incidence in 2020, 4371.48 in 2021, and 5043.74 in 2022, indicating that SLM model fit was higher than other models.

Regarding the regression coefficients of the composite vulnerability indicators, ADI had a significantly strong negative correlation with COVID-19 incidence in all years. SVI was negatively correlated with COVID-19 incidence in 2020 and 2021, with regression coefficients of −0.546 (z: −0.706, p: 0.48) and −4.464 (z: 5.753, p: 0.438) in 2021 in the SLM model but changed direction to a positive correlation of 4.163 (z: 0.179, p: 0.858) with COVID-19 incidence by June 2022. On the other hand, CCVI was significantly positively correlated with COVID-19 incidence in 2020 and 2021 in the SLM model with regression coefficients of 1.950 (z: 2.360, p: <.001) and 18.476 (z: 2.986, p: 0.003) in 2021, while the correlation changed to a negative correlation of −22.834 (z: −0.930, p: 0.352) with COVID-19 incidence by June 2022.

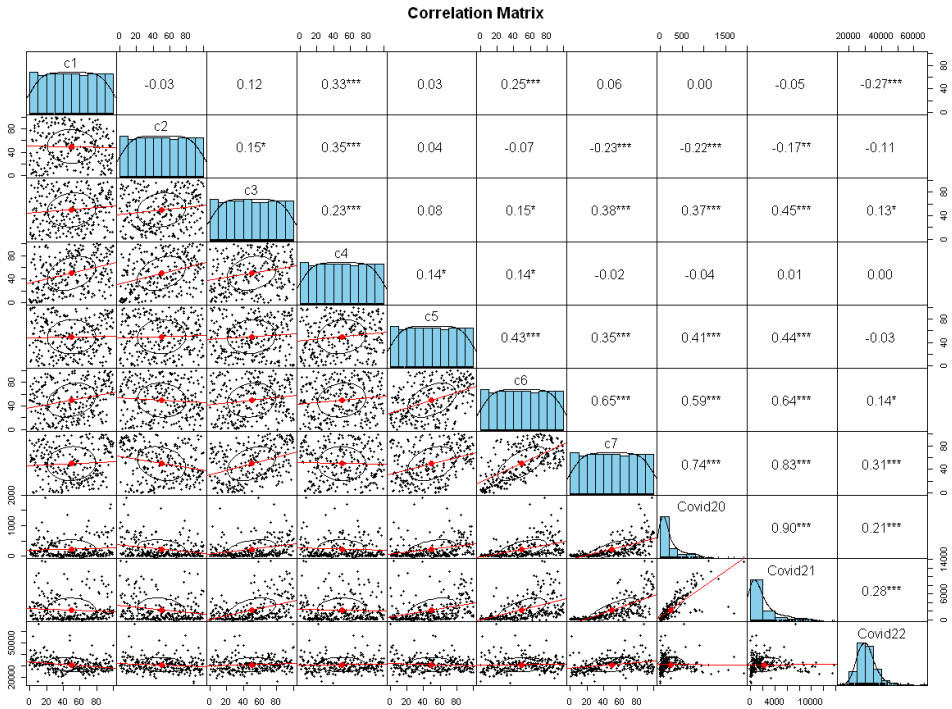
Table3 Regression table of the incidence rate of COVID-19 in association with 3 composite disadvantage indices

Variable	OLS		SLM		SEM	
	Coefft. (SE)	t (p)	Coefft. (SE)	Z (p)	Coefft. (SE)	z (P)
Dependent variable: Covid*19 incidence* in 2020						
intercept	349.708	6.842	108.041	2.467	262.407	4.459
	(51.110)	(<.001)	(43.797)	(0.014)	(58.845)	(<.001)
SVI	-1.145	-1.143	-0.546	-0.706	-0.715	-0.901
	(1.001)	(0.254)	(0.773)	(0.480)	(0.794)	(0.368)
ADI	-4.616	-7.124	-1.925	-3.505	-3.180	-4.418
	(0.648)	(<.001)	(0.549)	(<.001)	(0.720)	(<.001)
CCVI	3.401	3.215	1.950	2.360	2.547	2.844
	(1.058)	(0.001)	(0.826)	(0.018)	(0.896)	(0.004)
Ramda					0.693	13.000
					(0.053)	(<.001)
R2	0.332		0.597		0.596	
Log likelihood	-1731.190		-1680.990		-1684.037	
AIC	3470.380		3371.980		3376.070	
Dependent variable: Covid*19 incidence* in 2021						
intercept	3693.88	9.055	1028.830	3.024	2264.320	4.829
	(407.949)	(<.001)	(340.267)	(0.003)	(468.944)	(<.001)
SVI	-9.172	-1.148	-4.464	-0.776	-7.116	-1.198
	(7.992)	(0.252)	(5.753)	(0.438)	(5.941)	(0.231)
ADI	-51.371	-9.934	-19.055	-4.462	-26.425	-4.785
	(5.171)	(<.001)	(4.271)	(<.001)	(5.522)	(<.001)
CCVI	32.110	3.803	18.476	2.986	23.602	3.505
	(8.443)	(<.001)	(6.188)	(0.003)	(6.733)	(<.001)
Ramda					0.738	15.324
					(0.048)	(<.001)
R2	0.471		0.723		0.717	
Log likelihood	-2248.410		-2180.740		-2188.636	
AIC	4504.810		4371.480		4385.270	

Dependent variable: Covid*19 incidence* from January 1 2022 to 27 June 2022						
intercept	35710.6	29.158	29480	12.984	35817.9	27.420
	(1224.74)	(<.001)	(2270.53)	(<.001)	(1306.25)	(<.001)
SVI	2.301	0.096	4.163	0.179	8.259	0.346
	(23.994)	(0.924)	(23.222)	(0.858)	(23.841)	(0.729)
ADI	-74.178	-4.778	-64.467	-4.172	-77.028	-4.541
	(15.524)	(<.001)	(15.451)	(<.001)	(16.963)	(<.001)
CCVI	-23.323	-0.920	-22.834	-0.930	-29.581	-1.151
	(25.347)	(0.358)	(24.543)	(0.352)	(25.706)	(0.250)
Ramda					0.242	2.737
					(0.088)	(0.006)
R2	0.100		0.143		0.135	
Log likelihood	-2522.140		-2516.870		-2518.606	
AIC	5052.290		5043.740		5045.210	

In order to further investigate the relationship between CCVI sub-indices and COVID-19 incidence, Spearman correlation coefficients were computed. The findings revealed that population density (C7) exhibited a significant positive correlation with COVID-19 incidences across all periods. Similarly, the high-risk environment (C6), Housing and Environment (C3), and Healthcare system Factor (C5) demonstrated significant positive correlations with COVID-19 incidences in 2020 and 2021. However, the correlations between C6, C3, and COVID-19 incidences weakened in 2022. Conversely, Population and Household Characteristics (C2) displayed a weak negative correlation with COVID-19 incidences in 2020 and 2021. Notably, Epidemiological Factor (C4) did not exhibit any statistically significant correlations with COVID-19 incidences. Furthermore, Socioeconomic status (C1) displayed no correlation with COVID-19 incidences in 2020 and 2021. However, in the period of January to June 2022, a statistically significant weak negative correlation was observed between C1 and the incidence rate of COVID-19.

Figure5 Correlation plot between CCVI sub-indices and covid19 incidence by period



CCVI sub-indices (C1~7); C1: Socioeconomic status, C2: Population and Household Characteristics, C3: Housing and Environment, C4: Epidemiological Factor, C5: Healthcare system Factor, C6: High Risk Environment, C7: Population Density
Covid20: Covid-19 Incidence rate per 100,000 population in 2020, Covid21: Covid-19 Incidence rate per 100,000 population in 2021, Covid22: Covid-19 Incidence rate per 100,000 population from 1 January to 27 June 2022

Chapter 4. Discussion

The objective of this study was to examine the relationship between COVID-19 incidence and three composite disadvantage index values while also exploring spatial divergences and hotspots. The results confirmed the presence of spatial autocorrelation and demonstrated that the SLM model was the most effective in elucidating the association between COVID-19 incidence and index values.

This study revealed important insight into the relationship between composite disadvantage index scores and COVID-19 incidence in 2020 and 2021. In 2020, the SLM model demonstrated a statistically significant positive association between CCVI values and COVID-19 incidence (coefficient = 1.950, p = 0.018). In 2021, the SLM model confirmed this significant relationship with a coefficient of 18.476 (p = 0.003). These findings highlight the persistent impact of composite community vulnerability on the spread of COVID-19. Specifically, indicators within the CCVI, such as population density, high-risk environment, and household and transportation disruption, exhibited positive correlations with COVID-19 incidence. These results are consistent with prior research findings (Yun et al., 2021; Lee, 2023; Park et al., 2020) and underscore the importance of addressing these specific vulnerabilities in targeted public health interventions.

In 2022, a shift in the relationship between CCVI values and COVID-19 incidence was observed, as indicated by the SLM model. The coefficient for CCVI in 2022 was -22.834 (p = 0.352), signifying a lack of statistical significance. This implies that other factors or a transition to the endemic phase may have had a greater influence on the incidence of COVID-19 during the period. These findings emphasized the importance of ongoing surveillance and targeted interventions that address the identified vulnerabilities within the CCVI indicators. Additionally, it is crucial to take into account other potential factors that can impact disease transmission, as these factors may vary across different years.

The presence of hotspot areas in the CCVI aligning with regions experiencing COVID-19 outbreaks in both 2020 and 2021, such as Uijeongbu-si, Bucheon-si, Gwangmyeong-si, Siheung-si, Yangju-si, Anyang-si (Manan-gu), Ansan-si (Danwon-gu), and Goyang-si (Deokyang-gu), suggests a potential association between vulnerability and the occurrence of COVID-19 outbreaks. This suggests that areas with higher vulnerability may be at an increased risk of COVID-19 transmission or more susceptible to outbreaks.

However, further investigation is required to fully understand the relationship between incidence and vulnerability, as certain areas like Seongnam-gu, Guri-si, Gimpo-si, and Hanam-si, were not considered vulnerable areas or had high CCVI scores in either 2020 or 2021.

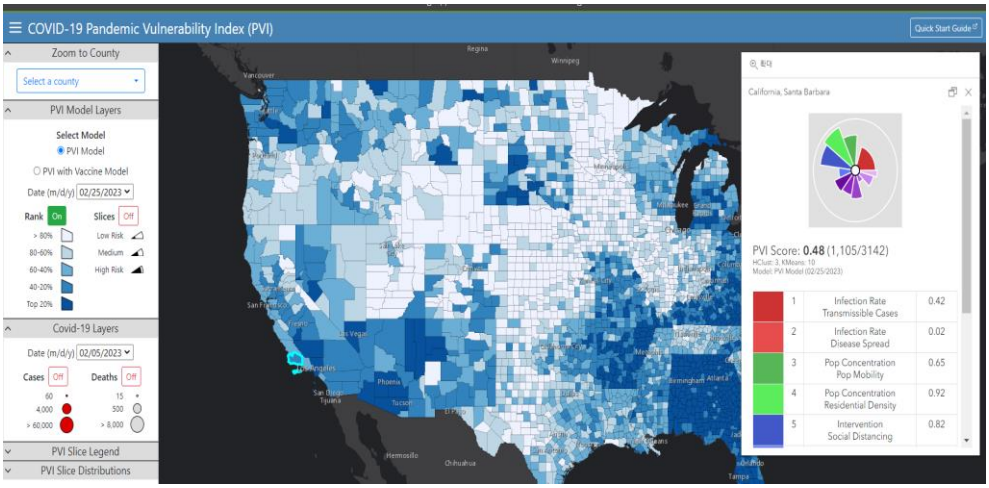
The Korean government implemented diverse strategies using a regional management approach that classified the country into metropolitan and non-metropolitan areas to mitigate the spread of COVID-19. However, as evident from the research findings, it is important to note that variations in vulnerability and incidence rates exist among different localities within the metropolitan region. Also, a study conducted by the Korea Institute of Land Research analyzed the incidence rate of COVID-19 across different subunits (Eup-Myeon-Dong) within Si-Gun-Gu. The results revealed significant correlations between the incidence rate and various factors, including resident population density, the proportion of multi-unit buildings, population per housing unit, the proportion of foreigners, and average monthly income per capita (estimated). These findings highlight the importance of conducting further research at subregional levels beyond city and district divisions, focusing on specific subdivisions or living areas, to gain a deeper understanding of the factors influencing COVID-19 transmission. Recognizing the significance of vulnerability in predicting and addressing the spread of the virus, it is anticipated that adopting evidence-based and efficient policy interventions, rather than relying on simplistic classifications, will be effective in managing the situation.

The United States CDC developed the PVI and enhanced the index and associated software to effectively control the rapid spread of infectious diseases. The PVI serves as a dashboard, facilitating decision-making and communication among government officials, scientists, and stakeholders. It provides a convenient platform for analyzing the correlation between regional vulnerability and COVID-19 incidence rates, enabling efficient monitoring and informed decision-making in response to the pandemic. (Figure 6).

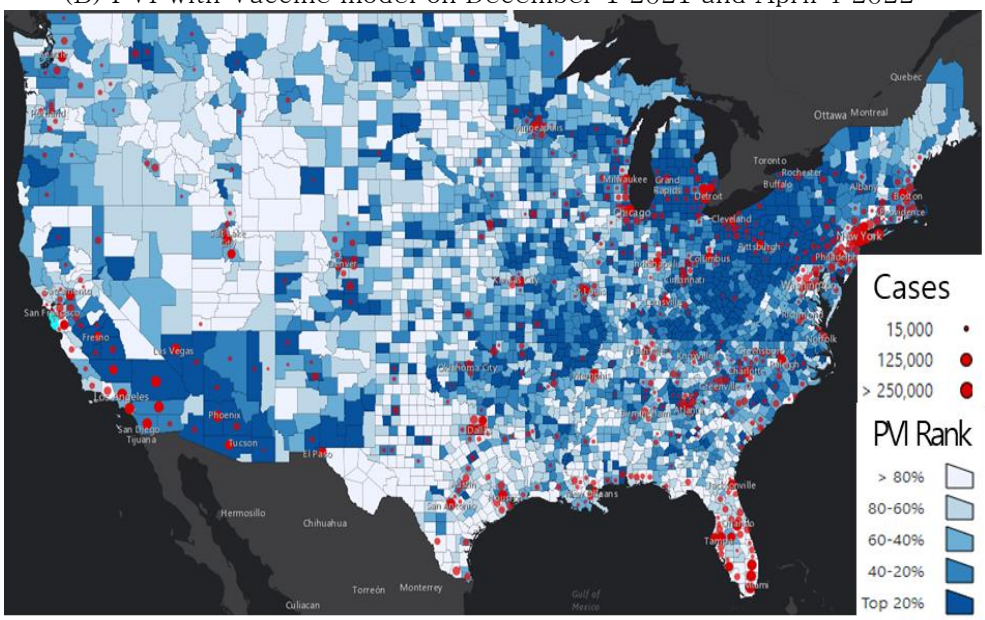
A preventive, integrated information system and big data platform are envisioned for medium to long-term planning for future pandemics. However, it is crucial to go beyond mere data compilation and prioritize effective communication that supports decision-making, like the PVI approach.

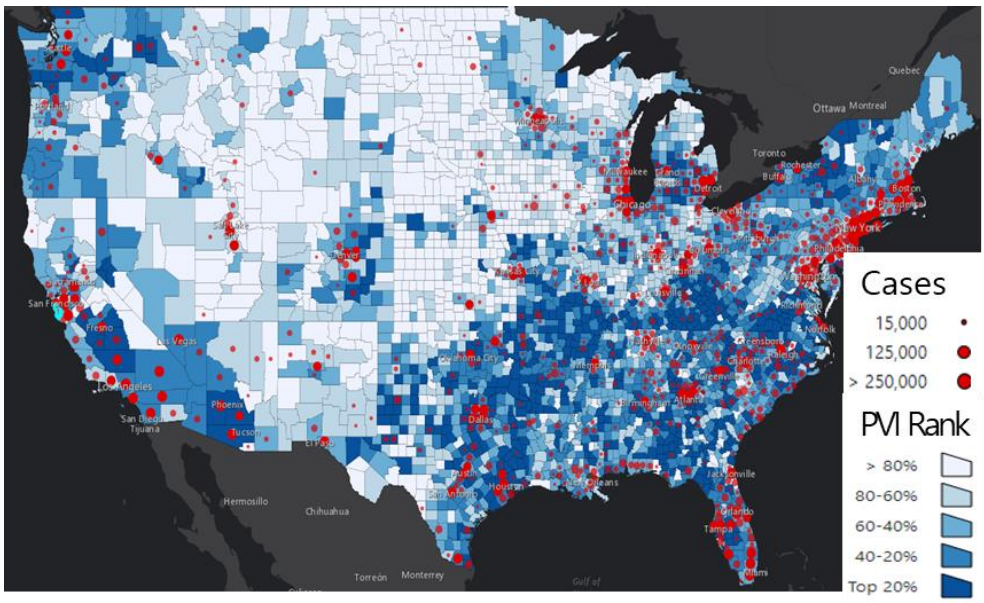
Figure6 Pandemic Vulnerability Index(PVI)

(A) PVI Dashboard



(B) PVI with Vaccine model on December 1 2021 and April 4 2022





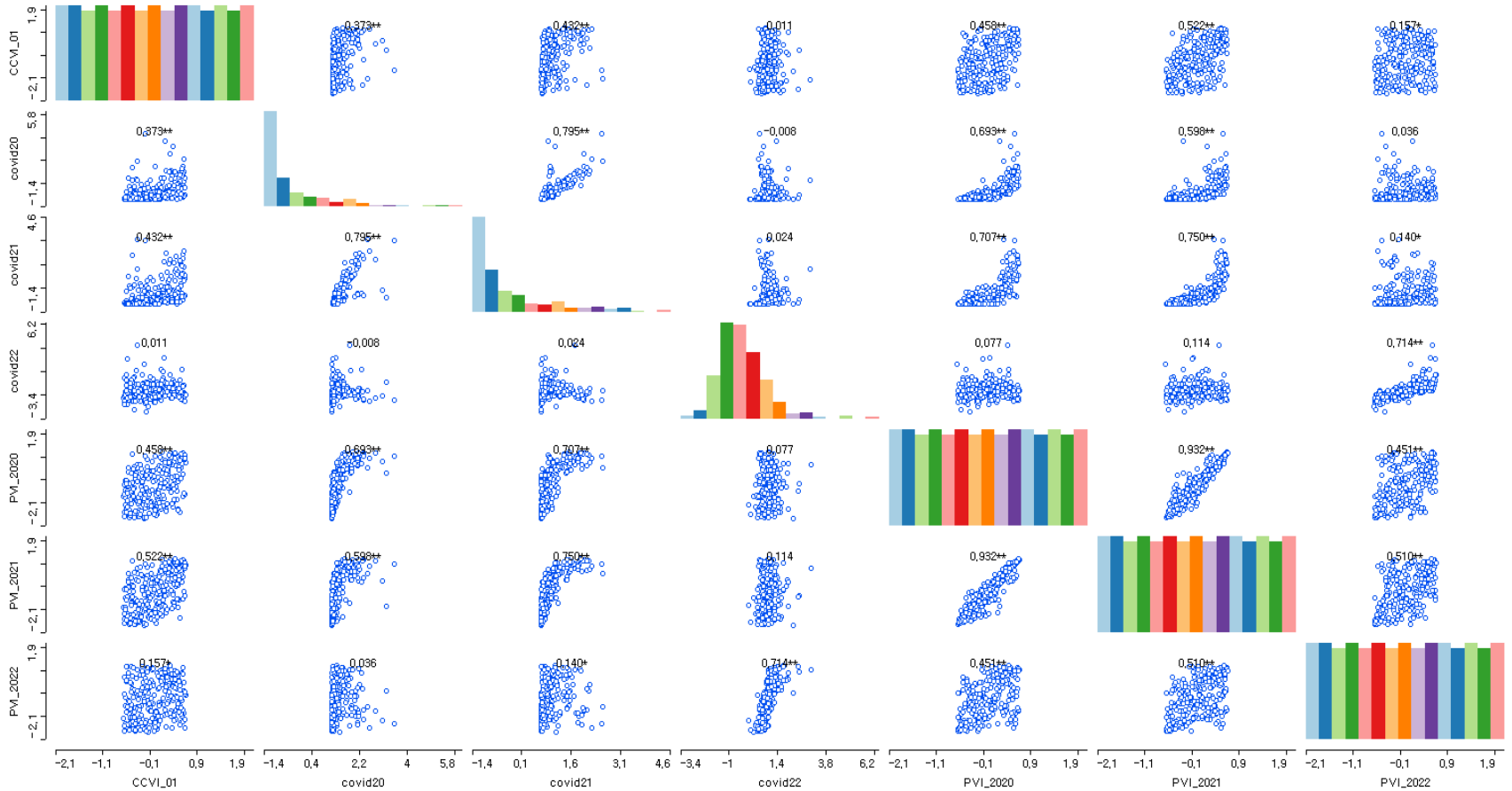
Source: https://covid19pvi.niehs.nih.gov/ search on 26 June 2023

Previously, the distancing tiers were based on a population of 100,000 and were adjusted according to the number of confirmed cases, allowing changes at the city and district levels (Central Disaster and Safety Countermeasures Headquarters for COVID-19, 2021.6.20). While sub-indicators, such as the infection reproduction index, rate of investigation of infection routes, rate of management within the prevention network, test positivity rate, number of critical care patients, and severity rate are considered, the composite disadvantage index, reflecting regional vulnerability, could serve as a valuable tool for evidence-based decision-making. Dynamic metrics will also allow local governments to comprehensively assess relevant factors to develop responses beyond social distancing. When the alert level of an infectious disease crisis is raised, it is essential to provide comprehensive data to enable local governments and other stakeholders to assess the situation effectively. The availability of comprehensive data ensures that decision-makers have access to all relevant information, allowing them to quickly understand the severity and nature of the crisis. Presenting comprehensive data facilitates a

rapid and accurate assessment of the situation, leading to the development and implementation of timely and appropriate response strategies.

When the PVI factors were adapted for South Korea through the modification and omission of certain data, a greater number of regions overlapped with COVID-19 hotspots compared to the CCVI (Appendix 5, 6). This suggests that the modified PVI may offer a more accurate depiction of areas with a higher risk of COVID-19 transmission. By incorporating additional factors and refining the index, the modified PVI has the potential to provide deeper insight into the relationship between vulnerability and COVID-19 outbreaks. The PVI incorporates cumulative incidence rates and recent two-week occurrence rates in its vulnerability calculation, making it a dynamic indicator that can better predict COVID-19 trends in specific regions compared to the static CCVI. By including standardized COVID-19 incidence rates, the PVI provides a more comprehensive assessment of the relationship between vulnerability and COVID-19 incidence. While the correlation between standardized COVID-19 incidence rates and CCVI appears to decrease in 2022 compared to 2020 and 2021, the PVI consistently shows correlations across all time periods. This highlights the robustness of the PVI in capturing the relationship between standardized COVID-19 incidence rates and vulnerability throughout different phases of the pandemic. (Figure 7) In Chicago, a Community Vulnerability Index was developed to define COVID-19 vaccine barriers (Chicago data portal, from https://data.cityofchicago.org/ on May 13, 2023). Central authorities can develop indicators, and, when necessary, local governments can operate them according to the specific needs of their regions. This allows for a tailored approach to providing relevant information and addressing specific challenges at the local level. These findings underscore the importance of continuously evaluating and updating vulnerability indices to enhance their effectiveness in comprehending and addressing public health challenges.

Figure7 Scatter plot matrix with CCVI, PVI, and COVID-19 incidence in 2020, 2021, and January-June 2022



In addition, it is crucial to focus on vulnerable areas or populations that may differ from those identified by traditional metrics. Discussions on vulnerable populations have been revitalized due to the impact of the COVID-19 pandemic (Robinson et al., 2021). This study identified positive correlations between various factors, including living in close quarters, population density, number of face-to-face workers, and residing in a long-term care facility, with COVID-19 incidence. Given the distinct characteristics of vulnerable groups, it is recommended that the mid to long-term regional healthcare plan, updated every four years, incorporates a specific item for calculating the local vulnerability index. This index can serve as a detailed performance indicator for disaster response, infectious disease management, and the establishment of a priority hierarchy. Regular monitoring and management of vulnerability index scores will enable more effective and targeted interventions to address the needs of vulnerable populations.

Limitation

This study has several limitations that need to be acknowledged. Firstly, the use of vulnerability indices (SVI, CCVI) designed for the United States may not accurately capture vulnerability at a regional level in South Korea. Some indicators had to be adapted or omitted, and it is uncertain whether these composite indices adequately reflect regional vulnerability in South Korea. Further research is necessary to address this issue. Also, Limitations of using composite indicators include potential data constraints, subjectivity in weighting factors, temporal aspect, complexity, and potential exclusion of certain vulnerability aspects in the composite disadvantage index.

Secondly, data limitations exist at a small-scale level, which may impact the assessment of spatial dynamics. Data collected based on administrative units may not fully capture the localized spread of infectious diseases within communities. Additionally, the availability of detailed factors, such as Korean language proficiency

data, was limited to the provincial level, leading to the exclusion of relevant factors.

Thirdly, confounding variables, such as government policies, subsidies, social distancing measures, seasonality, virus variants, and vaccinations, could have influenced the vulnerability and COVID-19 incidence rates but were not accounted for in this study. The exclusion of these factors may limit the comprehensive understanding of the relationship between vulnerability and COVID-19 incidence.

Lastly, while this study provides insights through spatial analysis of vulnerable groups, COVID-19 incidence rates, and vulnerability indices at the national and municipal levels, it is important to note that individual characteristics within specific regions are not represented in this study. Also, it is important to note that the analysis solely focused on the incidence rate as the dependent variable and did not consider other variables such as excess mortality or other indicators of vulnerability specific to each region. The vulnerability assessment and its correlation with the incidence rate were based solely on the selected variables and may not capture the entirety of the relationship between vulnerability and COVID-19 outcomes. To obtain a more comprehensive understanding, future analyses could incorporate additional dependent variables and consider a broader range of vulnerability factors specific to each region. This would provide a more nuanced assessment of the relationship between vulnerability and COVID-19 outcomes.

These limitations should be considered when interpreting the findings and further research is needed to address these limitations and enhance the understanding of vulnerability and COVID-19 transmission in South Korea.

Despite these limitations, this study has significance in identifying vulnerable areas during infectious disease outbreaks by using spatial analysis and contributing to the development of response policies, such as resource allocation, in the future.

Chapter 5. Conclusion

This study analyzed three composite vulnerability index (SVI, PVI, and ADI) values and the incidence rate of COVID-19 across 249 municipalities. Both the composite vulnerability index values and the incidence rate showed spatial autocorrelation. SVI and ADI scores exhibited a negative correlation, while PVI scores showed a positive correlation. By employing regression analysis models, namely ordinary least squares (OLS), the spatial lag model (SLM), and Structural Error Model (SEM), SLM was determined to be the most suitable method for explaining the incidence rate of COVID-19. This study provides a foundational understanding of the spatial correlation between municipal vulnerability index values and disease incidence rates, highlighting its significance. Future research should explore specific factors contributing to infectious disease vulnerability, considering geographic characteristics.

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Appendix 1] Social Vulnerability Index (SVI)

Domain	Variable	Additional Description	Resource
Socioeconomic Status	% individuals below poverty	% of persons below federally defined poverty line(below 50%), a threshold that varies by the size and age composition of the household. Denominator is total population where poverty status is checked.	American Community Survey (ACS), 2016-2020
	% civilian unemployed	Based on total population 16+. Civilian persons unemployed divided by total civilian population. Unemployed persons actively seeking work.	
	Per capita Income	The mean income is computed for every person in the census tract.	
	% of persons with no high school diploma	Percent of persons 25 years of age and older, with less than a 12th grade education (including individuals with 12 grades but no diploma).	
Household Composition/Disability	% of persons 65 years of age or older		
	% of persons 17 years of age or younger		
	% of persons more than 5 years old with a disability	% of civilian population not in an institution who are 5 years of age and older with a disability	
	% of male or female householder, no spouse present, with children under 18	Other family* male householder, no wife present, with own children under 18 years" *Other family: female householder, no husband present, with own children under 18 years"	
Minority Status/Language	Percent minority	Total of the following: "black or African American alone" +"American Indian and Alaska Native alone" + "Asian alone" + "Native Hawaiian and other Pacific Islander alone" + "some other race alone" + "two or more races" + "Hispanic or Latino – white alone.	
	English Language Fluence	For all age groups and all languages— the total of persons who speak English."not well" or "not at all."	
Housing/Transportation	% of multi-unit structure	% of housing units with 10 or more units in structure.	
	% of mobile homes	% of housing units that are mobile homes.	
	Crowding	At household level, more people than rooms. Percent total occupied housing units (i.e., households) with more than one person per room.	
	No vehicle available	% of households with no vehicle available.	
	% of persons in group quarters	% of persons who are in institutionalized group quarters (e.g., correctional institutions, nursing homes) and non-institutionalized group quarters (e.g., college dormitories, military quarters).	

Appendix 2] Korean Area Deprivation Index (ADI)

Variable	Description	Source
Poor households	% of all household members in households where the head is engaged in agriculture/fishery as a self-employed worker, a simple laborer, or an employee among all members are aged 15-64 years	POPULATION AND HOUSING CENSUS
Unemployed	% of population with less than a high school diploma aged between 15 and 64 years	
Elder	% of older adults aged ≥ 65 years	
Divorced or separated	% of divorced or separated population aged ≥ 15 years	
Single households	% of Single household among the total households	
Female head of household	% of Female head of household among the total households	
Living without apartment	% of households not living in apartments	
Poor housing condition	% of households without a modern-style separate kitchen, a private bathroom, a private bath, an independent water supply, or a water heating system	
Living without apartment	% of households not living in apartments	

Appendix 3] Covid19 Community vulnerability index (CCVI)

Domain	Variable	Indicator(s)	Geo Precision	Source
Socioeconomic Status	Below Poverty	Persons below poverty estimate	Census Tract	CDC, American Community Survey (ACS), 2014-2018
	Unemployed	Civilian (age 16+) unemployed estimate		
	Income	Per capita income estimate		
	No High School Diploma	Persons with no high school diploma (age 25+) estimate		
	Uninsured	% of population uninsured		
Minority Status & Language	Minority	Minority (all persons except white, non-Hispanic) estimate		
	Speaks English “Less than Well”	Persons (age 5+) who speak English "less than well" estimate		
Housing type, Transportation, Household Composition & Disability	Multi-Unit Structures	Housing with structures with 10 or more units estimate		
	Crowding	Households with more people than rooms estimate		
	No Vehicle	Households with no vehicle available estimate		
	Group Quarters	Persons in institutionalized group quarters estimate		
	Aged 17 or Younger	Persons aged 17 and younger estimate		
	Single-Parent Households	Single-parent households with children under 18 estimate		
	Access to Indoor Plumbing	Households without access to indoor plumbing		
	Mobile Homes	Mobile homes estimate		
	Older than Age 5with a Disability	Civilian noninstitutionalized population with a disability estimate		
Epidemiological Factors	Cardiovascular Conditions	% of adults diagnosed with high cholesterol	Census Tract (2017)	Policy Map: CDC, Behavioral Risk Factor Surveillance System (BRFSS), 2017-2018
		% of adults diagnosed with a stroke	Census Tract (2018)	
		% of adults ever diagnosed with heart disease		
	Respiratory Conditions	% of adults diagnosed with chronic obstructive pulmonary disease, emphysema, or chronic bronchitis	Census Tract (2018)	
		% of adults reporting to smoke cigarettes		

	Immuno-compromised	Annual cancer incidence per 100,000 persons	County	PolicyMap: CDC, National Cancer Institute (NCI), 2011-2015
		% of persons living with an HIV diagnosis per 100,000 people		PolicyMap: CDC, National Center for HIV, STD and TB Prevention (NCHSTP), Division of STD/HIV Prevention, 2016
	Obesity	% of adults reporting to be obese (a body mass index of 30 or greater)	Census Tract (2018)	PolicyMap: CDC, Behavioral Risk Factor Surveillance System (BRFSS), 2018
	Diabetes	% of adults ever diagnosed with diabetes	Census Tract (2018)	
	Aged 65 or Older	Persons aged 65 and older estimate	Census Tract	CDC, American Community Survey (ACS), 2014-2018 5-Year Estimates
Healthcare System Factors	Health System Capacity	Intensive Care Unit (ICU) Beds per 100,000 population	County	Kaiser Health News, Centers for Medicare, & Medicaid Services (CMS), 2018-2019
		Hospital Beds per 100,000 population	State	Definitive Healthcare, 2020
		Epidemiologists per 100,000 population		U.S Bureau of Labor Statistics (BLS), Occupational Employment and Wages, May 2018
	Health System Strength	Agency for Healthcare Research and Quality - Prevention Quality Indicator Overall Composite (PQI): admission rates for preventable conditions (via good outpatient care) adjusted per population	County	Centers for Medicare, & Medicaid Services (CMS), Mapping Medicare Disparities (MMD) Tool, 2017
		Health Spending per Capita	State	Centers for Medicare, & Medicaid Services (CMS), Health Expenditures by State of Residence, 2014

		Aggregate cost of medical care	Census Tract	PolicyMap & Quantitative Innovations, 2017
	Healthcare Accessibility	% of population with a Primary Care Physician	Census Tract	PolicyMap & CDC BRFSS, 2018
	Health System Preparedness	Total Public Health Emergency Preparedness (PHEP) Funding Per Capita	State	CDC, Center for Preparedness and Response, 2019
		Health Labs per 100,000 population	County	Association of Public Health Laboratories
Healthcare System Factors	Health System Preparedness	Emergency Services per 100,000 population	State	Census, Economic Annual Surveys, 2017
High Risk Environments	% of population working or living in environments with high infection risk	Long-term care (nursing homes, assisted living, and care homes) residents per 100,000	Census tract	ArcGIS/Dept of Homeland Security
		Prisons population per 100,000	County	Vera institute for Justice, 2016
		% of population employed in high-risk industry	County	BLS QCEW 2020
Population Density	Population Density	Estimated total number of people per unit area (sq. miles)	Census Tract	CDC Social Vulnerability Index

Appendix 4] Data resources for composite disadvantage indices and covid19 incidence

Domain	Variable	Description	Resources
Socioeconomic status	Below Poverty	% of population belonging to household with incomes below 50% of the median monthly household income*	Korea Centers for Disease Control and Prevention, Community Health Survey, 2019 raw data
	Income per capita	Average Gross Regional Domestic Product per capita	Statistics Korea (Regional Statistics Planning Team), 2019, 25 February 2023, GRDP (city, county, district)
	Poor households	% of all household members in households where the head is engaged in agriculture/fishery as a self-employed worker, a simple laborer, or an employee among all members are aged 15-64 years	Statistics Korea, 「Census of Population and Housing」, 2020,2023.02.24, Census_2%_Population (Provided)_2020
	Unemployed	% of Unemployed population aged ≥ 16 years	Statistics Korea, 「Census」, 2020, 2023.02.25, Population by sex and economically active status
	No high school Diploma	% of population with no high school diploma aged ≥ 25 years	Statistics Korea, "Population Census", 2020, 29.04.2023, Population by sex, age, marital status, and educational attainment (15 years and over, in-country) - City, District
		% of population with less than a high school diploma aged between 15 and 64 years	
Population & Household Characteristics	Younger	% of population aged ≤ 17 years	Statistics Korea, "Population Census", 2020, 30.04.2023, Population by age and sex - Towns and villages (year end 0,5), cities and districts
	Single-Parent Households	% of single-parent household with no married children aged <18 years	Ministry of Health and Welfare, 2020, 25.02.2023, Number of single-parent families by family type, number of recipients (2020.12)
	Divorced or separated	% of divorced or separated population aged ≥ 15 years	Statistics Korea, "Population Census", 2020, 29.04.2023, Population by sex, age, marital status, and educational attainment (15 years and over, in-country) - city, county, and district

	Single households	% of Single household among the total households	Statistics Korea, "Population Census", 2020, 25.02.2023, Households by gender, household composition, and marital status of household head
	Female head of household	% of female head of household among the total households	
	Population with disability	% of population not in an institution who are 5 years of age and older with a disability	Statistics Korea, "Population Census", 2020, 25.02.2023, Population by Gender and Type of Activity Limitation
	Foreigner	% of foreigner not Korean nationality or not from OECD among the total registered foreigners	Ministry of Justice, 2019, 2023.3.30, Foreigner Residents Statistics
Housing & Environment	Non-residential buildings	% of households living in inadequate housing conditions; Hotels, inns, and other lodging facilities, Dormitories and special communal facilities, Makeshift structures such as shacks and plastic houses, Other (temporary residences such as sleeping quarters in businesses or makeshift structures on construction sites)	Statistics Korea, 「Housing Survey」, 2021, 2023.03.30, Type of Dwelling and Residence, Households, Household Members - Municipalities
	Multi unit-structure	% of households living in single-family houses with 10 or more households or in multi-family houses	Statistics Korea, 「Census of Population and Housing」, 2020,2023.04.24, Population and Housing Census_2%_Household Details (Provided)_2020
	Crowding	% of occupied housing units (i.e., households) with more than one person per room	Statistics Korea, 「Census」, 2020, 25.02.2023, Households by number of household members and number of rooms/living room/dining room
	Group Quarters	% of households that unrelated households of 6 or more people or Institutional households *	Statistics Korea, 「Census」, 2020, 25.02.2023, Households and Household Members by Household Type - Towns and Villages
	Living without apartment	% of households not living in apartments	Statistics Korea, "Population Census", 2020, 25.02.2023, Households by type of place of residence and type of housing accommodation

	Poor housing condition	% of households without a modern-style separate kitchen, a private bathroom, a private bath, an independent water supply, or a water heating system	
	No indoor Plumber	Percentage of households without access to indoor plumbing	
	No Vehicle	% of households with no vehicle	Statistics Korea, "Population Census", 2020, 25.02.2023, Households by car parks
Epidemiological Factor	Elder	% of older adults aged ≥ 65 years	Statistics Korea, "Population Census", 2020, 30.04.2023, Population by age and sex - towns and villages (year end 0,5), cities and districts
	Cardiovascular Conditions	% of adults diagnosed with hypertension	Korea Centers for Disease Control and Prevention, 「Community Health Survey」, 2019, 13.05.2023, Experience rate of hypertension diagnosis by city, county, and district (30 years and older)
		% of adults recognized with early symptom of myocardial infarction	Korea Centers for Disease Control and Prevention, 「Community Health Survey」, 2019, 2023.05.13, Prevalence of recognition of early symptoms of myocardial infarction by city, county, and district
		% of adults recognized with early symptom of stroke	Korea Centers for Disease Control and Prevention, 「Community Health Survey」, 2019, 2023.05.13, Early symptom recognition rate of stroke (hemorrhagic stroke) by city, county, and district
		% of adults hospitalized with Angina	Korea National Institutes of Health, 2019, 2023.5.13, 2019 Health Map Indicators
	Respiratory Conditions	% of adults hospitalized with chronic obstructive pulmonary disease	
		% of current smokers ("smoking every day" or "smoking sometimes") among individuals who have smoked 5 packs (100 cigarettes) or more in their lifetime (up to now) adjusted using standard population (2005 estimated population, Statistics Korea)	Korea Centers for Disease Control and Prevention, 「Community Health Survey」, 2019, 2023.02.25, Current smoking rate by city, county, and district
	Immuno-compromised	Age-standardized cancer(C00-C96) incidence per 100,000 persons from 2013 to 2018	Ministry of Health and Welfare, 「Cancer Registration Statistics」, 2018, 13.05.2023, Number of cancer cases, relative frequency, crude

			incidence rate, and age-standardized incidence rate by city, county, and district for 24 cancer types/gender
		% of population living with an HIV diagnosis per 100,000 people	Ministry of Health and Welfare, "National Health Statistics", 2015, 13.05.2023, Number of hospitalized patients by patient residence and disease group
	Obesity	% of population who reports a body mass index (BMI) greater than or equal to 25 kg/m2 adjusted using standard population (2005 estimated population, Statistics Korea)	Korea Centers for Disease Control and Prevention, 「Community Health Survey」, 2019, 2023.02.25, Obesity prevalence by city, county, and district
	Diabetes	% of population with diabetes diagnosed by doctor≥ 30 years	Korea Centers for Disease Control and Prevention, 「Community Health Survey」, 2019, 2023.02.25, Diabetes diagnosis experience rate by city, county, and district
Healthcare system Factor	Health System Capacity	Intensive Care Unit (ICU) Beds per 100,000 population	National Health Insurance Service (Customer Service Operation Department), 2019, 25.02.2023, Number of medical institution beds per thousand population (province, city, county, district)
		Hospital Beds per 100,000 population	National Health Insurance Service (Customer Service Operation Department), 2019, 25.02.2023, Number of medical institution beds per thousand population (province, city, county, district)
	Health System Strength	Preventable hospitalization rates by healthcare provider location	National Health Insurance Service, "Medical Utilization Statistics by Region", 2019, 13.05.2023, Medical Institutions by City and District
		Health spending per capita	
		Aggregate cost of medical care	
	Accessibility	General practitioners per 100,000 people	National Health Insurance Service, 「Medical Utilisation Statistics by Region」, 2019, 2023.05.13, Medical Personnel by City and District
	Health System Preparedness	% of Financial Independence of Local Government	National Institutes of Health, 2019, 2023.5.13, 2019 Health Map Indicators
		Clinical examination per 100,000 population	National Health Insurance Service, Health Insurance Review and Evaluation Service, "Health Insurance Statistics", 2019 4/4,

		Emergency beds per 100,000 population	2023.05.13, Status of specialized treatment rooms by city and district
High Risk Environment	environments with high	Long-term care residents per 100,000 population	Ministry of Health and Welfare, 2023.5.13, 2019, Number of welfare facilities by facility type
	infection risk	Percentage of population employed in high-risk industry	Statistics Korea, "Population Census", 2020, 2023.05.22, Employed population (15 years old and over) by residence, workplace, and occupation - city and district
Population Density	Population Density	Estimated total number of people per unit area (sq. kilometers)	Ministry of the Interior and Safety, "Korean Urban Statistics", 2019, 2023.03.03, Population and population density by sex and age
Covid19 incidence		Covid 19 incidence per 100,000 population in 2020 and 2021	Korea Centers for Disease Control and Prevention, “Infectious Disease Surveillance Annals”, 2020, 2021, 2023.05.13, Novel Infectious Disease Syndrome Outbreaks
		Covid 19 incidence per 100,000 population from 1 January to 27 June 2022	Korea Centers for Disease Control and Prevention, COVID-19 outbreaks by region

Appendix 5] Compostie disadvantage indices Score for SVI, ADI , and CCVI in Si-Gun-Gu

Korea name	English name	Code	SVI	ADI	CCVI	Korea name	English name	Code	SVI	ADI	CCVI
종로구	Jongno-gu	11110	0.302	0.008	0.197	영월군	Yeongwol-gun	42750	0.068	0.785	0
중구	Jung-gu	11140	0.258	0.141	0.213	평창군	Pyeongchang-gun	42760	0.048	0.797	0.032
용산구	Yongsan-gu	11170	0.318	0.024	0.375	정선군	Jeongseon-gun	42770	0.08	0.906	0.024
성동구	Seongdong-gu	11200	0.532	0.097	0.625	철원군	Cheorwon-gun	42780	0.088	0.57	0.161
광진구	Gwangjin-gu	11215	0.423	0.028	0.838	화천군	Hwacheon-gun	42790	0.016	0.558	0.056
동대문구	Dongdaemun-gu	11230	0.56	0.145	0.846	양구군	Yanggu-gun	42800	0.024	0.566	0.004
중랑구	Jungnang-gu	11260	0.79	0.315	0.979	인제군	Inje-gun	42810	0.004	0.554	0.044
성북구	Seongbuk-gu	11290	0.733	0.157	0.935	고성군	Goseong-gun	42820	0.092	0.854	0.076
강북구	Gangbuk-gu	11305	0.883	0.408	0.971	양양군	Yangyang-gun	42830	0.004	0.765	0.008
도봉구	Dobong-gu	11320	0.729	0.36	0.903	청주시상당구	Sangdang-gu,Cheongju-si	43111	0.241	0.267	0.12
노원구	Nowon-gu	11350	0.838	0.534	0.923	청주시서원구	Seowon-gu,Cheongju-si	43112	0.237	0.489	0.233
은평구	Eunpyeong-gu	11380	0.758	0.02	0.907	청주시흥덕구	Heungdeok-gu,Cheongju-si	43113	0.052	0.287	0.314
서대문구	Seodaemun-gu	11410	0.395	0.048	0.423	청주시청원구	Cheongwon-gu,Cheongju-si	43114	0.358	0.263	0.302
마포구	Mapo-gu	11440	0.185	0.089	0.612	충주시	Chungju-si	43130	0.971	0.672	0.826
양천구	Yangcheon-gu	11470	0.794	0.016	0.842	제천시	Jecheon-si	43150	0.754	0.696	0.411
강서구	Gangseo-gu	11500	0.512	0.19	0.758	보은군	Boeun-gun	43720	0.29	0.834	0.27
구로구	Guro-gu	11530	0.81	0.275	0.967	옥천군	Okcheon-gun	43730	0.572	0.728	0.338

금천구	Geumcheon-gu	11545	0.745	0.279	0.959	영동군	Yeongdong-gun	43740	0.919	0.801	0.588
영등포구	Yeongdeungpo-gu	11560	0.629	0.186	0.689	증평군	Jeungpyeong-gun	43745	0.213	0.635	0.294
동작구	Dongjak-gu	11590	0.798	0.06	0.947	진천군	Jincheon-gun	43750	0.584	0.542	0.483
관악구	Gwanak-gu	11620	0.544	0.198	0.963	괴산군	Goesan-gun	43760	0.274	0.753	0.306
서초구	Seocho-gu	11650	0.145	0.012	0.133	음성군	Eumseong-gun	43770	0.447	0.724	0.677
강남구	Gangnam-gu	11680	0.241	0.032	0.221	단양군	Danyang-gun	43800	0.084	0.684	0.125
송파구	Songpa-gu	11710	0.225	0.004	0.35	천안시동남구	Dongnam-gu,Cheonan-si	44131	0.637	0.582	0.395
강동구	Gangdong-gu	11740	0.52	0.113	0.649	천안시서북구	Seobuk-gu,Cheonan-si	44133	0.366	0.327	0.604
중구	Jung-gu	26110	0.701	0.716	0.685	공주시	Gongju-si	44150	0.895	0.574	0.524
서구	Seo-gu	26140	0.866	0.368	0.641	보령시	Boryeong-si	44180	0.818	0.688	0.439
동구	Dong-gu	26170	0.491	0.348	0.6	아산시	Asan-si	44200	0.495	0.485	0.737
영도구	Yeongdo-gu	26200	0.947	0.655	0.955	서산시	Seosan-si	44210	0.528	0.562	0.443
부산진구	Busanjin-gu	26230	0.588	0.331	0.85	논산시	Nonsan-si	44230	0.963	0.659	0.854
동래구	Dongnae-gu	26260	0.399	0.182	0.637	계룡시	Gyeryong-si	44250	0	0.514	0.04
남구	Nam-gu	26290	0.669	0.255	0.875	당진시	Dangjin-si	44270	0.741	0.457	0.661
북구	Buk-gu	26320	0.483	0.53	0.794	금산군	Geumsan-gun	44710	0.931	0.748	0.596
해운대구	Haeundae-gu	26350	0.479	0.238	0.693	부여군	Buyeo-gun	44760	0.6	0.846	0.54
사하구	Saha-gu	26380	0.907	0.384	0.991	서천군	Seocheon-gun	44770	0.56	0.862	0.528

금정구	Geumjeong-gu	26410	0.806	0.178	0.721	청양군	Cheongyang-gun	44790	0.282	0.838	0.181
강서구	Gangseo-gu	26440	0.141	0.125	0.451	홍성군	Hongseong-gun	44800	0.354	0.781	0.217
연제구	Yeonje-gu	26470	0.616	0.242	0.798	예산군	Yesan-gun	44810	0.423	0.773	0.157
수영구	Suyeong-gu	26500	0.451	0.295	0.681	태안군	Taean-gun	44825	0.205	0.769	0.096
사상구	Sasang-gu	26530	0.883	0.55	0.975	전주시완산구	Wansan-gu,Jeonju-si	45111	0.391	0.372	0.399
기장군	Gijang-gun	26710	0.552	0.425	0.584	전주시덕진구	Deokjin-gu,Jeonju-si	45113	0.35	0.17	0.334
중구	Jung-gu	27110	0.294	0.323	0.165	군산시	Gunsan-si	45130	0.822	0.607	0.858
동구	Dong-gu	27140	0.786	0.497	0.766	익산시	Iksan-si	45140	0.987	0.639	0.802
서구	Seo-gu	27170	0.802	0.364	0.943	정읍시	Jeongeup-si	45180	0.939	0.817	0.701
남구	Nam-gu	27200	0.77	0.506	0.665	남원시	Namwon-si	45190	0.58	0.813	0.342
북구	Buk-gu	27230	0.459	0.404	0.745	김제시	Gimje-si	45210	0.927	0.894	0.814
수성구	Suseong-gu	27260	0.314	0.101	0.508	완주군	Wanju-gun	45710	0.826	0.623	0.762
달서구	Dalseo-gu	27290	0.608	0.433	0.806	진안군	Jinan-gun	45720	0.193	0.842	0.012
달성군	Dalseong-gun	27710	0.387	0.481	0.778	무주군	Muju-gun	45730	0.06	0.947	0.02
중구	Jung-gu	28110	0.439	0.668	0.318	장수군	Jangsu-gun	45740	0.157	0.87	0.084
동구	Dong-gu	28140	0.415	0.627	0.657	임실군	Imsil-gun	45750	0.37	0.967	0.245
미추홀구	Michuhol-gu	28177	1	0.437	1	순창군	Sunchang-gun	45770	0.161	0.85	0.06
연수구	Yeonsu-gu	28185	0.032	0.133	0.467	고창군	Gochang-gun	45790	0.362	0.898	0.411

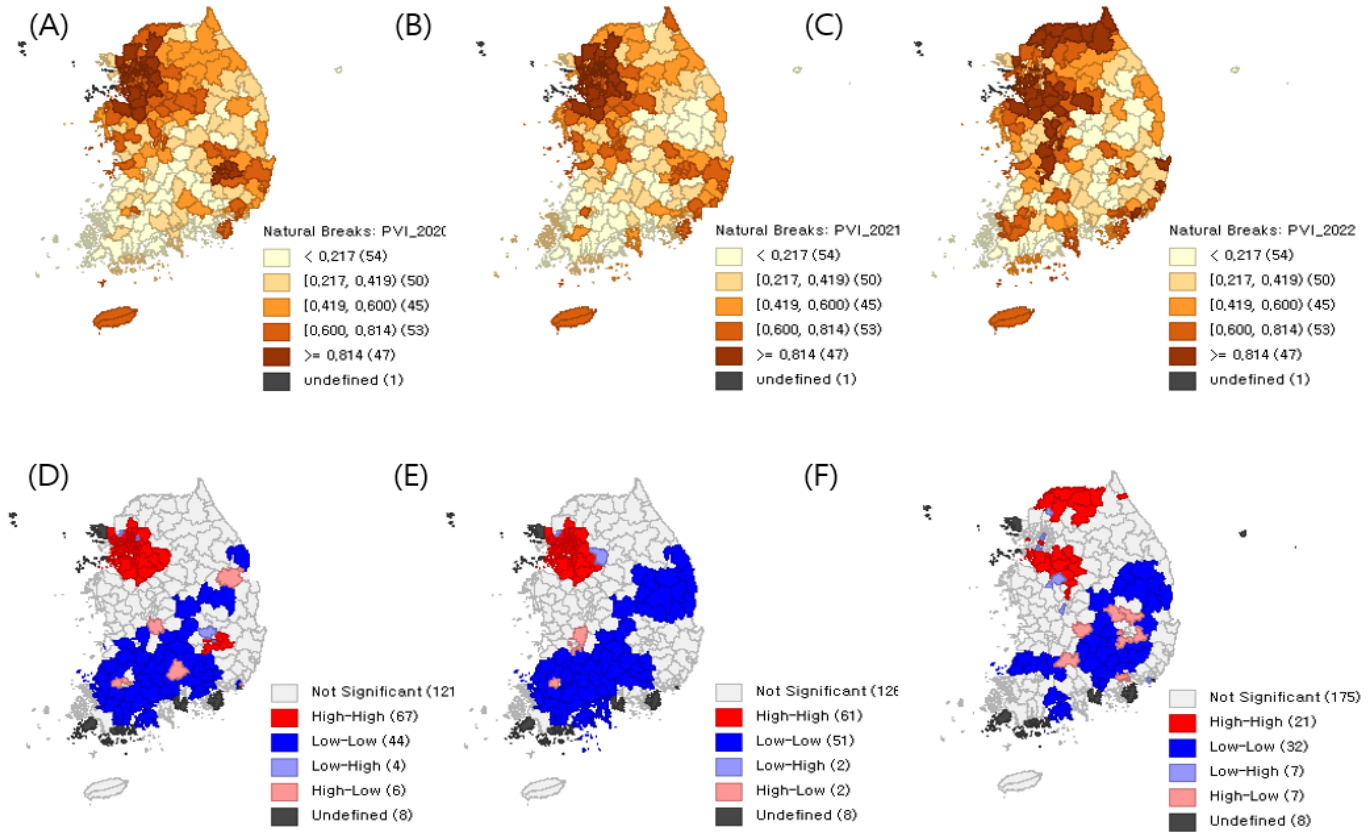
남동구	Namdong-gu	28200	0.995	0.246	0.987	부안군	Buan-gun	45800	0.217	0.923	0.205
부평구	Bupyeong-gu	28237	0.979	0.271	0.995	목포시	Mokpo-si	46110	0.903	0.793	0.915
계양구	Gyeyang-gu	28245	0.475	0.311	0.709	여수시	Yeosu-si	46130	0.774	0.587	0.79
서구	Seo-gu	28260	0.673	0.117	0.911	순천시	Suncheon-si	46150	0.379	0.473	0.447
강화군	Ganghwa-gun	28710	0.891	0.4	0.536	나주시	Naju-si	46170	0.508	0.821	0.479
동구	Dong-gu	29110	0.689	0.218	0.62	광양시	Gwangyang-si	46230	0.169	0.522	0.266
서구	Seo-gu	29140	0.096	0.336	0.403	담양군	Damyang-gun	46710	0.725	0.449	0.516
남구	Nam-gu	29155	0.233	0.591	0.391	곡성군	Gokseong-gun	46720	0.375	0.858	0.149
북구	Buk-gu	29170	0.782	0.299	0.891	구례군	Gurye-gun	46730	0.108	0.951	0.092
광산구	Gwangsan-gu	29200	0.516	0.174	0.81	고흥군	Goheung-gun	46770	0.87	0.987	0.544
동구	Dong-gu	30110	0.951	0.518	0.951	보성군	Boseong-gun	46780	0.149	1	0.088
중구	Jung-gu	30140	0.915	0.477	0.645	화순군	Hwasun-gun	46790	0.181	0.91	0.112
서구	Seo-gu	30170	0.536	0.356	0.512	장흥군	Jangheung-gun	46800	0.125	0.971	0.25
유성구	Yuseong-gu	30200	0.278	0.109	0.387	강진군	Gangjin-gun	46810	0.209	0.919	0.258
대덕구	Daedeok-gu	30230	0.62	0.453	0.721	해남군	Haenam-gun	46820	0.25	0.983	0.326
중구	Jung-gu	31110	0.556	0.093	0.629	영암군	Yeongam-gun	46830	0.31	0.886	0.419
남구	Nam-gu	31140	0.137	0.04	0.532	무안군	Muan-gun	46840	0.133	0.68	0.108
동구	Dong-gu	31170	0.04	0.105	0.31	함평군	Hampyeong-gun	46860	0.27	0.882	0.189

북구	Buk-gu	31200	0.173	0.085	0.459	영광군	Yeonggwang-gun	46870	0.661	0.74	0.52
울주군	Ulju-gun	31710	0.487	0.165	0.608	장성군	Jangseong-gun	46880	0.403	0.631	0.427
세종시	Sejong-si	36110	0.116	0.251	0.298	완도군	Wando-gun	46890	0.858	0.809	0.862
수원시장안구	Jangan-gu,Suwon-si	41111	0.713	0.21	0.786	진도군	Jindo-gun	46900	0.411	0.979	0.427
수원시권선구	Gwonseon-gu,Suwon-si	41113	0.504	0.376	0.754	신안군	Sinan-gun	46910	0.455	0.939	0.362
수원시팔달구	Paldal-gu,Suwon-si	41115	0.834	0.493	0.633	포항시남구	Nam-gu,Pohang-si	47111	0.709	0.417	0.705
수원시영통구	Yeongtong-gu,Suwon-si	41117	0.229	0.064	0.237	포항시북구	Buk-gu,Pohang-si	47113	0.431	0.538	0.556
성남시수정구	Sujeong-gu,Seongnam-si	41131	0.576	0.429	0.729	경주시	Gyeongju-si	47130	0.991	0.445	0.899
성남시중원구	Jungwon-gu,Seongnam-si	41133	0.431	0.421	0.669	김천시	Gimcheon-si	47150	0.85	0.704	0.548
성남시분당구	Bundang-gu,Seongnam-si	41135	0.064	0.08	0.072	안동시	Andong-si	47170	0.697	0.736	0.241
의정부시	Uijeongbu-si	41150	0.911	0.526	0.939	구미시	Gumi-si	47190	0.346	0.259	0.576
안양시만안구	Manan-gu,Anyang-si	41171	0.677	0.214	0.709	영주시	Yeongju-si	47210	0.842	0.619	0.407
안양시동안구	Dongan-gu,Anyang-si	41173	0.116	0.076	0.08	영천시	Yeongcheon-si	47230	0.899	0.874	0.673
부천시	Bucheon-si	41190	0.967	0.072	0.983	상주시	Sangju-si	47250	0.814	0.943	0.229
광명시	Gwangmyeong-si	41210	0.693	0.153	0.717	문경시	Mungyeong-si	47280	0.975	0.708	0.29
평택시	Pyeongtaek-si	41220	0.306	0.502	0.741	경산시	Gyeongsan-si	47290	0.737	0.615	0.83
동두천시	Dongducheon-si	41250	0.846	0.441	0.883	군위군	Gunwi-gun	47720	0.588	0.744	0.495
안산시상록구	Sangnok-gu,Ansan-si	41271	0.705	0.121	0.927	의성군	Uiseong-gun	47730	0.645	0.995	0.491

안산시단원구	Danwon-gu,Ansan-si	41273	0.721	0.226	0.697	청송군	Cheongsong-gun	47750	0.076	0.975	0.1
고양시덕양구	Deogyang-gu,Goyang-si	41281	0.649	0.307	0.77	영양군	Yeongyang-gun	47760	0.197	0.955	0.064
고양시일산동구	Ilsandong-gu,Goyang-si	41285	0.266	0.068	0.141	영덕군	Yeongdeok-gun	47770	0.596	0.991	0.568
고양시일산서구	Ilsanseo-gu,Goyang-si	41287	0.056	0.222	0.104	청도군	Cheongdo-gun	47820	0.467	0.959	0.185
과천시	Gwacheon-si	41290	0.072	0	0.116	고령군	Goryeong-gun	47830	0.326	0.914	0.145
구리시	Guri-si	41310	0.322	0.137	0.358	성주군	Seongju-gun	47840	0.286	0.825	0.346
남양주시	Namyangju-si	41360	0.87	0.38	0.919	칠곡군	Chilgok-gun	47850	0.189	0.603	0.463
오산시	Osan-si	41370	0.612	0.469	0.774	예천군	Yecheon-gun	47900	0.177	0.761	0.052
시흥시	Siheung-si	41390	0.653	0.202	0.879	봉화군	Bonghwa-gun	47920	0.044	0.878	0.016
군포시	Gunpo-si	41410	0.524	0.23	0.572	울진군	Uljin-gun	47930	0.443	0.643	0.33
의왕시	Uiwang-si	41430	0.165	0.194	0.137	울릉군	Ulleung-gun	47940	0.407	0.412	0.173
하남시	Hanam-si	41450	0.104	0.319	0.262	창원시의창구	Uichang-gu,Changwon-si	48121	0.036	0.056	0.177
용인시처인구	Cheoin-gu,Yongin-si	41461	0.637	0.34	0.75	창원시성산구	Seongsan-gu,Changwon-si	48123	0.012	0.044	0.036
용인시기흥구	Giheung-gu,Yongin-si	41463	0.129	0.149	0.286	창원시마산합포구	Masanhappo-gu,Changwon-si	48125	0.665	0.291	0.435
용인시수지구	Suji-gu,Yongin-si	41465	0.028	0.036	0.169	창원시마산회원구	Masanhoewon-gu,Changwon-si	48127	0.548	0.161	0.37
파주시	Paju-si	41480	0.862	0.392	0.834	창원시진해구	Jinhae-gu,Changwon-si	48129	0.197	0.129	0.383
이천시	Icheon-si	41500	0.568	0.388	0.379	진주시	Jinju-si	48170	0.745	0.546	0.58
안성시	Anseong-si	41550	0.879	0.578	0.616	통영시	Tongyeong-si	48220	0.983	0.712	0.87

김포시	Gimpo-si	41570	0.766	0.344	0.866	사천시	Sacheon-si	48240	0.54	0.651	0.451
화성시	Hwaseong-si	41590	0.604	0.206	0.822	김해시	Gimhae-si	48250	0.959	0.283	0.931
광주시	Gwangju-si	41610	0.685	0.052	0.733	밀양시	Miryang-si	48270	0.854	0.805	0.818
양주시	Yangju-si	41630	0.951	0.51	0.895	거제시	Geoje-si	48310	0.02	0.352	0.354
포천시	Pocheon-si	41650	0.935	0.465	0.592	양산시	Yangsan-si	48330	0.342	0.461	0.564
여주시	Yeoju-si	41670	0.923	0.595	0.475	의령군	Uiryeong-gun	48720	0.713	0.866	0.274
연천군	Yeoncheon-gun	41800	0.633	0.692	0.552	함안군	Haman-gun	48730	0.62	0.72	0.487
가평군	Gapyeong-gun	41820	0.5	0.396	0.282	창녕군	Changnyeong-gun	48740	0.83	0.757	0.782
양평군	Yangpyeong-gun	41830	0.681	0.234	0.471	고성군	Goseong-gun	48820	0.774	0.732	0.5
춘천시	Chuncheon-si	42110	0.657	0.611	0.56	남해군	Namhae-gun	48840	0.221	0.829	0.504
원주시	Wonju-si	42130	0.419	0.599	0.322	하동군	Hadong-gun	48850	0.262	0.935	0.153
강릉시	Gangneung-si	42150	0.762	0.663	0.653	산청군	Sancheong-gun	48860	0.334	0.902	0.225
동해시	Donghae-si	42170	0.463	0.7	0.278	함양군	Hamyang-gun	48870	0.298	0.89	0.254
태백시	Taebaek-si	42190	0.338	0.789	0.209	거창군	Geochang-gun	48880	0.153	0.931	0.048
속초시	Sokcho-si	42210	0.254	0.963	0.129	합천군	Hapcheon-gun	48890	0.383	0.927	0.193
삼척시	Samcheok-si	42230	0.33	0.777	0.201	제주시	Jeju-si	50110	0.943	0.303	0.887
홍천군	Hongcheon-gun	42720	0.108	0.676	0.028	서귀포시	Seogwipo-si	50130	0.471	0.573	0.366
횡성군	Hoengseong-gun	42730	0.1	0.647	0.068						

Appendix 6] Map and Local Moran’ s I of Pandemic Vulnerability Index(PVI)



(A) PVI in 2020, (B) PVI in 2021 (C) PVI in 2022.1.1~6.27
(D) Local Moran’s I PVI in 2020 (E) Local Moran’s I PVI in 2021 (F) Local Moran’s I PVI in 2022.1.1~.6.27

Appendix 7] Description of the amended Pandemic Vulnerability Index(PVI)

Data Domain (% weight) Data Slice (% weight) Component(s)			Description/Rationale	Source(s)
Infection Rate (25%)				
			Confirmed cases by period(2020. 2021, 22.1.1~6.27)	Korea Centers for Disease Control and Prevention
Population Concentration (15%)				
Population Mobility (10%)				
Daytime Population Density	Static		% of estimated daytime population% of estimated daytime population	2020 Population and Housing Census
Population mobility	Static		% of estimated mobile communication and population mobility	2020 County Health Rankings
Residential Density (5%)				
Residential Density	Static		Integrates data from the 2020 Population and Housing Census on families in multi-unit structures, Non-residential building, over-crowding (more people than rooms), being without a vehicle, and persons in institutionalized group quarter.	2020 Population and Housing Census
Health & Environment (35%)				
Hospital Beds (10%)				

	Static		% of hospital beds per 1,000 persons	2019 Regional Healthcare utilization statistics
Hospital Ventilators (10%)				
	Static		% of ventilators across all medical facilities per 1,000 persons	2019 Regional Healthcare utilization statistics
Population Demographics (3%)				
% Foreigner	Static		% of foreigners not Korean nationality or not from OECD among the total registered foreigners	2019 Foreigner Arrival and Departure Statistics
Air Pollution (3%)				
	Static		Average daily density of fine particulate matter in micrograms per cubic meter (PM2.5)	2019 Air Korea
Age Distribution (3%)				
% age 65 and over	Static		% of older adults aged ≥ 65 years	2020 Population and Housing Census
Co-morbidities (3%)				
Premature death	Static		Average life expectancy from 2014 to 2019	2019 Health Insurance
Smoking	Static		% of population who are current smokers	2019 Community Health

Diabetes	Static		% of population with diagnosed diabetes	Survey
Obesity	Static		% of population who are reports a body mass index (BMI) greater than or equal to 25 kg/m2	
Health Disparities (3%)				
SVI Socioeconomic Status	Static		Integrates data from 2019 Community Health Survey on percent below poverty, 2020 Population and Housing Census on percent unemployed (historical), income, and percent without a high school diploma	2020 Population and Housing Census

국문초록

코로나19 발생률과 복합 취약 지수들 간의 공간 분석

김 보 은
보건학과 보건학전공
서울대학교 보건대학원

연구배경: 코로나19 비상조치는 2023년 5월 중단되었으나, 코로나로 인해 많은 확진자와 사망자가 발생하였고, 이로 인한 건강영향과 취약계층에 대한 탐색이 필요한 실정이다. 다만, 공간분석을 사용한 연구는 거의 없어 이에 본 연구는 복합 취약성 지수를 활용하여 코로나19 발생률에 미치는 요인을 연구함으로써 시군구 단위에 적합한 보건 정책의 근거를 제공하고자 한다.

연구방법: 시군구별 코로나19 확진자, 복합 합취약성 지수를 사용하여 분포를 확인하였다. Moran's I를 통하여 공간자기상관성을 확인하고, 복합 취약성 지수들과 코로나19 시기별 확진자 수간의 상관관계 분석을 위해 공간 회귀 분석을 OLS, SLM, SEM 모델을 이용하여 시행하였다. 복합 취약성 지수 세부 요인과 시기별 발생률 간의 상관분석을 하였다.

연구결과: 옹진군을 제외한 249개의 시군구별 코로나19 발생률이 양의 공간자기상관성(2020년 Morans' I=0.601, 2021년 Moran's I=0.743, 2022.1~6, Moran's I = 0.160)으로 나타났고, 복합 취약성 지수들도 양의 공간자기상관성을 보였다. (SVI Morans' I=0.206, ADI Moran's I=0.703, CCVI Moran's I = 0.385), 각 복합 취약성 지수의 시군구별 핫스팟 확인 및 코로나19 발생률과 복합취약지수들 간의 공간회귀 분석을 수행하였고, CCVI가 양의 상관관계를 보였다.

모형 적합 측면에서 SLM의 결정 계수 값이 2020년 0.597, 2021년 0.723, 2022년 0.143으로 모든 시기 높았고, AIC값도 2020년 −1680.99, 2021년 −2180.74, 2022년 −2516.87으로 모든 시기 낮게 나타났다.

결론: 249개 시군구의 취약성 지수를 확인하고, 시기별 핫스팟이 상이함과 CCVI가 시기별 코로나19 발생률과 양의 상관성이 있음을 확인하였다. 이와 관련하여 코로나19와 같은 감염병 대응을 위해 시군구별 취약요인을 고려한 대응책 마련이 필요하다고 하겠다.

주요어 : 코로나19, 발생률, 공간 분석, 복합 취약성 지수

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