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Exploratory study on the spatial relationship between emerging infectious diseases and urban characteristics: Cases from Korea

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ABSTRACT

In the modern global context of interconnected populations, the recent emergence of infectious diseases involves complex interactions. The purpose of this study is to investigate the spatial correlations between urban characteristics, taking into account the socio-ecological aspects, and the emergence of infectious diseases. Using exploratory spatial data analysis and spatial regression between the infectious disease emergence data and 14 urban characteristics, we analyzed 225 spatial units in South Korea, where there was a re-emergence of measles and a 2015 outbreak of Middle East Respiratory Syndrome. As results of exploratory spatial data analysis, the emerging infectious diseases had spatial dependence and showed spatial clusters. Spatial regression models showed that urban characteristic factors had different effects according to the type of infectious disease. Common factors were characteristics related to low socioeconomic status in water or food-borne diseases and manageable infectious diseases. Intermittent infectious disease epidemics are related to high-quality residential environments and the response capacity of the local government. New infectious diseases are different than other infectious diseases, which are related to the ecological environment. This study suggests spatial policies for preventing infectious diseases considering the spatial relationships between urban characteristics and infectious diseases as well as the management of public health.

1. Introduction

Despite breakthroughs in infectious disease management, the emergence of new infectious diseases such as SARS (Severe Acute Respiratory Syndrome) and Influenza A virus subtype H1N1 is posing a new risk to public health (World Health Organization, 2014). Infectious diseases do not merely cause mortality, but also have a greater socioeconomic impact than ever before (Jones et al., 2008; Keil & Ali, 2007; World Health Organization, 2014). Cities that have experienced rapid urbanization and unplanned growth in particular have been extensively affected by emerging or re-emerging infectious diseases (Moore, Gould, & Keary, 2003; Neiderud, 2015; Wang, 2021). The current emergence of infectious diseases is the product of factors accompanying complex interactions among numerous variables (Institute of Medicine of the National Academies, 2003; Wilcox & Gubler, 2005). In order to understand the mechanisms related to the emergence and re-emergence of infectious diseases, it is necessary to understand the interconnected natural and human systems, as well as the complex interactions within such systems (Finucane, Fox, Sakserna, & Spencer, 2014).

Infectious diseases and public health have long been discussed within urban studies or planning (Giles-Corti et al., 2016; Northridge & Sclar, 2003). The garden city proposed by Ebenezer Howard in 19th-century England was an effort to create a residential environment protected from infectious diseases (Clark, 2003). Dr. John Snow, who discovered the cause of cholera in 1854, created the first spatial analysis linking infectious disease emergence to urban environmental factors (Brody, Rip, Vinten-Johansen, Paneth, & Rachman, 2000). Recently, improving urban capacity to prevent and control infectious diseases following their emergence is resurfacing as an important issue, and the need to integrate infectious disease management policies with urban planning is gathering support (Alirol et al., 2011; Neiderud, 2015). In particular, the urban population is increasing, and the growth of modern cities has

Abbreviations: AIDS, Acquired Immune Deficiency Syndrome; CJD, Creutzfeldt-Jakob disease; CRE, Carbapenem-resistant Enterobacteriaceae; EID, emerging infectious diseases; HFRS, haemorrhagic fever with renal syndrome; HH, High-High; HL, High-Low; LH, Low-High; LISA, Local Indicators of Spatial Association; LL, Low-Low; MERS, Middle East Respiratory Syndrome; MOHW, Ministry of Health and Welfare; MRPA, multidrug-resistant pseudomonas aeruginosa; MRSA, methicillin-resistant Staphylococcus aureus; SARS, Severe Acute Respiratory Syndrome; SFTS, severe fever with thrombocytopenia syndrome; VRE, vancomycin-resistant enterococci; VRSA, vancomycin-resistant Staphylococcus aureus.

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become a potential risk in terms of infectious disease emergence (Neiderud, 2015; Tong et al., 2015), creating a demand for research on social and ecological factors affecting emerging infectious diseases (EID) (Wilcox & Colwell, 2005; Wilcox & Gabler, 2005).

The recent emergence of COVID-19, which has been continuously and rapidly spreading, has caused serious damage worldwide (Harapan et al., 2020). Various policies have been applied to each country and city to prevent the spread. Many studies currently being conducted focus on elucidating the epidemiological characteristics of confirmed cases of COVID-19 in specific cities. This topic has mainly been approached from a medical perspective and attends to the descriptive characteristics of infectious agents and pathways (Hoang, Hoang, Khuong, La, & Tran, 2020; Lee et al., 2020). Some case studies have been conducted on COVID-19 that evaluate environmental factors such as temperature, precipitation, and population density (Byass, 2020), link reduction and deindustrialization characteristics (Krzysztofik, Kantor-Pietraga, & Spórna, 2020), and identify spatial characteristics with mapping and spatial analysis (Dejardins, Hohl, & Delmelle, 2020; Moens, Raposo, Feringa, Kraak, & Kölben, 2020). However, these studies focus on the descriptive patterns of COVID-19 but do not take into account the relationship between existing and new infectious diseases and the factors of infectious disease related to urban characteristics.

The purpose of this study is to investigate the spatial correlation between infectious disease outbreaks and urban characteristics, taking into account their socio-ecological aspects. South Korean cities are the subjects of the analysis, and this study used local government units of city/county/district (si/gun/gu). South Korea was selected because of its degree of urbanization and the apparent emergence or re-emergence of infectious diseases. Korea has undergone rapid urbanization since its industrialization in the 1960s, and 81.9% of the population resides in urban areas as of 2009 (OECD, 2012). Furthermore, beyond the epidemic of Middle East Respiratory Syndrome (MERS) in 2015 (Jack, 2015), additional phenomena such as the re-emergence of measles in approximately 50,000 people from 2000 to 2001 have been observed (Park et al., 2013).

Section 2 will examine the urban factors affecting the emergence of infectious diseases through a literature review, and Section 3 will present the analytic method of exploratory spatial data analysis and spatial regression models along with the data used. Section 4 will present results showing the relationship between infectious diseases and urban characteristics, and Section 5 will present the study conclusions, the implications for urban planning regarding the prevention of infectious diseases, and the study limitations.

2. EID and urban characteristics

EID occur when agents reach a host from the external environment through various means of transmission and reproduce therein (Asaria & MacMaho, 2006; Kim, 2013; Kutsuna & Hayakawa, 2013; World Health Organization, 2004). Bhopal presented the interaction among the host, agent, and environment in an ecological model called the epidemiological triangle, which has been used to analyze this causal relationship and to derive public health strategies (Bhopal, 2002). The urban environment associated with the spread of diseases, infectious or otherwise, includes not only human food, drinking water, and air, but also houses, workplaces, family members, health care facilities, and people who provide emotional or financial support (Gales, Freudenberg, & Vlahov, 2005; Mei et al., 2015; Zhang, Huang, Duarte, & Zhang, 2016). The Institute of Medicine (Institute of Medicine of the National Academies, 2003) explains that such environments are largely divided into areas such as genetic and biological, physical environmental, ecological, and political and socioeconomic fields and that individual factors associated with the emergence of infectious diseases are included in one or more of these four fields.

Processes involving the transmission and evolution of pathogens in the context of infectious disease emergence include those involving the ecosystem and regional environmental changes on a global scale (Santos-Vega, Martinez, & Pascual, 2016; Wilcox & Gabler, 2005). While traditionally an area of ecology or system ecology, this process has recently expanded into the socio-ecological perspective (Jones, Betson, & Pfeiffer, 2017; Wilcox & Gabler, 2005). This socio-ecological perspective not only deals with the dynamic behavior of complex and large-scale systems but also theoretically links the fields of biology and social sciences (Semenza, Sudre, Oni, Suk, & Giesecke, 2013; Wilcox & Gabler, 2005). The blueprint by Wilcox and Colwell (2005), which reflects these perspectives and describes the environmental factors associated with the emergence of infectious diseases, shows not only the failure of disease control and public health policies, but also the demographic and social agents in the regional environmental changes worldwide, with an emphasis on urbanization, agricultural intensification, and habitat alteration driven by population growth and consumption.

Increases in population and resource consumption resulting in waste generation, as well as changes to land use and cover, play a significant role in the emergence of infectious diseases (McFarlane, Leigh, & McMichael, 2013; Shah, Huxley, Elmes, & Murray, 2019; Wilcox & Colwell, 2005; Wilcox & Ellis, 2006; Wilcox & Gabler, 2005). Although this pattern varies by location, it can alter the ecosystem through urbanization, agricultural intensification, and habitat alteration, thereby affecting pathogens, animal hosts, and human societies (Finucane et al., 2014; Semenza et al., 2013; Wilcox & Colwell, 2005; Wilcox & Gabler, 2005). Moreover, the changes in these "host-pathogen" relationships cause pathogen spillovers to new hosts, rapid adaptation of agents, frequent production, and an increase in range of variants of new pathogens causing emergence or re-emergence of infectious diseases as well as increase in the intensity and frequency of existing diseases (Finucane et al., 2014).

Factors associated with urban characteristics in the emergence of infectious diseases have been presented in some previous studies; Table 1 summarizes the causes of infectious disease emergence linked to urban characteristics based on prior research.

3. Materials and methods

3.1. Exploratory spatial data analysis

This study used Local Moran’s I, the Local Indicators of Spatial Association (LISA) proposed by Anselin (1995), to determine the spatial correlation between urban characteristics and EID. The spatial cluster map of EID and the cluster map of the urban characteristics related to EID presented in previous studies were examined. Next, a correlation analysis was conducted between the LISA value of EID weighted with spatial characteristics and the LISA value of urban characteristics to verify the correlation between the two variables. The LISA value weighted with spatial characteristics considering the attribute values of the surrounding area was used to verify the correlation in this study for the following reasons. One is that EID has the attribute of spreading over a certain spatial range at the city level (Wilcox & Colwell, 2005; Wilcox & Gabler, 2005), and the other is that the attribute of cities related to EID is also related to the surrounding area.

Cluster maps using LISA are classified into four types of spaces (Anselin, 1995; Gongxin & Zaiheng, 2011). The High-High (HH) type indicates high observation values recorded for the surrounding areas of a region with high observation values, and the Low-Low (LL) type indicates low observation values recorded in the surrounding areas of a region with low observation values. The High-Low (HL) type indicates areas with high observation values but low observation values for its surrounding areas, and the Low-High (LH) type indicates areas with low observation values but high observation values recorded for its surrounding areas.

Local Moran’s I is calculated in Eq. (1). Spatial weight was determined through the queen’s case, which sets the weighted value based on
neighboring units sharing any point among contiguity-based weighting calculation methods (Anselin, 2005).

$$I_i = y = \sum_j W_{ij} y_j$$  \hspace{1cm} (1)

$$y_i : \text{Attribute value of variables in } i\text{-region, } y_j : \text{Attribute value of variables in } j\text{-region, } W_{ij} : \text{Spatial adjacency weight for I and j regions}$$

### 3.2. Spatial regression model

This study used the spatial regression model to understand how the variables of urban characteristics affect EIDs. When there is spatial dependence in which the values of variables are related to each other between spatial units, the OLS estimator of a linear regression model does not become BLUE (Best Linear Unbiased Estimator). In the case of spatial dependence, the spatial regression model by Anselin (2002) was used to determine a more unbiased estimate. The spatial regression model can be divided into two models, the spatial lag model and spatial error model, based on the type of spatial dependence. The spatial lag model is used in the case of spatial dependence of the dependent variable. To control the spatial dependence, a spatial variable ($W_0$) was added to the spatial lag model of Eq. (2) and we used the maximum likelihood estimation considering endogenous problems.

$$y = \rho W_0 + X\beta + \varepsilon, \varepsilon \sim N(0, \sigma^2 I)$$  \hspace{1cm} (2)

$$y: n \times 1 \text{ matrix of dependent variable, } X: n \times k \text{ matrix of independent variable, } W_0: n \times n \text{ spatial weight matrix, } \rho: \text{spatial error parameter, } \beta: k \times 1 \text{ of regression parameter, } \varepsilon: \text{matrix of error term}$$

The spatial error model was applied with the spatial error term ($W_0$) of Eq. (3) in the case of spatial dependence of the error term in OLS model. The estimating method of the spatial error model was the general method of moments.

$$y = X\beta + \varepsilon, \varepsilon = \lambda W_0 + \mu$$  \hspace{1cm} (3)

Table 1

| Factor   | Factor Type                  | Description                                                                 |
|----------|------------------------------|-----------------------------------------------------------------------------|
| Biological| [1, 5, 10, 30]               | • Older adults and infants are more vulnerable to infectious diseases due to age-associated immunosuppression. |
| Host     | [1, 2, 9, 15, 17, 19, 25, 27]| • Certain infectious diseases are affected by an individual’s socioeconomic status to a greater degree than by their location. |
| Constitutional| [1, 6, 10, 15, 27, 30]     | • Social inequalities (poverty, land, housing, malnutrition, and access to infrastructure and information) affect the distribution of infectious diseases. |
| Proliferation| [2, 8, 11, 14, 15, 23, 30, 31]| • Changes in eating habits (unsanitary dietary life, fast-food, take-out) affect the emergence of infectious diseases. |
| Pathogenesis| Transmission [2, 3, 11, 14, 16, 18, 22, 23, 26, 28, 31]| • Individual immune response against diseases induces the production of cells and protective antibodies. |
| Physical| [2, 4, 7, 12, 15, 18, 20, 21, 23, 24, 26, 29]| • Changes in medicine technology contribute to antibiotic resistance, thereby increasing infectious diseases. |
| Environmental| Economic [2, 12, 13, 15, 18, 21, 23, 28, 29]| • Increase in survival time and agent population due to climate change influences diseases likely to emerge in specific climates. |
| Ecological| [3, 7, 15, 18, 22, 28, 31, 32]| • There is an increase in survival time and agent population due to changes in land use and ecological and living environments. |

This study used the total EID data from two years of 2016 and 2017—when all were significant, a robust LM-lag test and a robust LM-error test, and if all were significant, a robust LM-lag test and a robust LM-error test were additionally performed, and a model was selected based on the results (Yang, 2010). In this study, the EID was used as the dependent variable and the urban characteristics factors were used as the independent variables.

### 3.3. Unit of analysis and data

The unit of analysis is each of the 225 city/county/districts forming the local governments in South Korea. There are 229 city/county/districts in South Korea, including 10 islands. In this study, we excluded four areas—Ongjin-gun, Ulleung-gun, Jeju-si, and Seogwipo-si—which are not connected via an overland route.

This study used the total EID data from two years of 2016 and 2017 and urban characteristic’s values of 2010 for each city/county/district provided by Statistics Korea. Data from the Korea Meteorological Administration (2012) were used for climate-related factors. The EID classification was categorized according to the criteria defined by the Ministry of Health and Welfare (MOHW). The Ministry of Health and Welfare (2017) classifies EID into six types according to the vector, prevention, and epidemic potential of the infectious diseases (Table 2). In this study, Group 1–4 infectious diseases were used, corresponding to those subjected to mandatory surveillance; designated infectious
diseases and the Group 5 sentinel surveillance infectious diseases were excluded.

Indicators and measurement variables related to urban characteristics, shown in Table 3, were derived based on the linkage factors of previous studies discussed in Table 1. The urbanization factor in the regional environmental change proposed by Wilcox and Colwell (2005), along with the public health infrastructure, capacity, and climate factors that may show mutual influence, was divided into the three EID factors of host, agent, and environment within the framework proposed by Bhopal (2002). Indicators and measurement variables were constructed based on the collective characteristics related to host and external factors indicated in the environment. In this study, the agent varies according to the behavior of the host, its organic relationship with the environment, and the agent mechanism; as this study does not include a dynamic analysis, the agent factor was excluded. Climate-related factors included 10-year average values for the number of days with the highest average daily temperature of no less than 33 °C (heat wave); the number of days with the lowest average daily temperature of no less than 25 °C (tropical night); and the number of days with an average daily precipitation of no less than 80 mm.

4. Results

4.1. Spatial cluster of EID

The emergence of infectious diseases, which was classified into four groups, was found to have different spatial correlations for each group (Fig. 1). The Moran’s I for Group 1 infectious diseases was 0.507, and a clearly distinguishable spatial pattern was seen between the HH cluster and LL cluster, and HH cluster regions were formed with conurbation within the south and west of the capital region (Seoul, Gyeonggi, and Incheon) and New City for Public Administration (Sejong city). The Moran’s I for Group 2 infectious diseases was 0.351, and HH areas with high emergence of Group 2 infectious diseases consisted of the conurbation of western Seoul such as Seoul-Bucheon-Incheon, southern Seoul and Gyeonggi, and parts of metropolitan areas such as Busan. The Moran’s I for Group 3 infectious diseases was 0.289, and HH regions were formed in two distinct regions: the surrounding region of southern Seoul and the surrounding region of Busan. The Group 3 HH clusters showed characteristics of groups connected across several cities. In the case of Group 4 infectious diseases, the Moran’s I was 0.237 and the HH cluster region centered around Seoul. The southeastern cities in the capital region were connected, and they formed a wide HH cluster. The northeastern cities in the capital region formed an HH cluster.

4.2. Descriptive statistics

Table 4 shows the descriptive statistics of the dependent and independent variables for each model used in this study. As the dependent variable, the number of confirmed infected people was used for each group’s EID and total EID. The EID of Group 2 was the highest on average, and the EID of Group 4 was the lowest. In addition, the standard deviation between 225 regions was high in Groups 2 and 3. In host factors of the urban characteristics affecting EID, the average value of the older adult population was 33,370, the average value of the infant population was 9735.38, and the average value of the number of national basic living security recipients was 6790.67. The average value of the ratio of semi-basement households was 1.66, and the average value of the ratio of the population with a maximum of elementary school graduation was 20.51. Concerning environmental factors, the imperious area ratio and population density differed according to the characteristics of the region. Days with the lowest average daily temperature no less than 25°C between 2000 and 2010 showed slightly larger averages and standard deviations.

4.3. Spatial relationships between EID and urban characteristics

In this study, in identifying the spatial relationship between EID and urban characteristics, the validity of applying the spatial regression model was examined through OLS estimation of the linear model and Lagrange multiplier, as shown in Table 5. First, in the results of the OLS regression analysis including all variables, H1, H2, E1, and E3 had values of VIF above 10, and these four variables were excluded from the analysis due to multicollinearity. Next, the EID of all infectious diseases was defined as model 1, the EID of infectious diseases in each group was defined as models 2–5, and analysis was performed. As a result of tests such as Jarque-Bera, Breusch-Pagan, and Koenker-Bassett, the spatial regression model was found to be more suitable for estimation in all models. By testing the LM-lag and LM-error values, the method of including the spatial dependence variable for each model can be

| Class | Characteristics | Type |
|-------|----------------|------|
| Group 1 | Water or food-borne outbreaks (epidemics) Immediate preventive measures required (6 types) | Cholera, typhoid, paratyphoid, shigellosis, enterohemorrhagic Escherichia coli infection, hepatitis A |
| Group 2 | Infectious diseases prevented and managed through immunization. Subject to National Immunization Program (12 types) | Diphtheria, pertussis, tetanus, measles, mumps, rubella, polio, hepatitis B, Japanese B encephalitis, chickenpox, hemophilus influenza type b, streptococcus pneumoniae |
| Group 3 | Continuous outbreak monitoring and preventive measures required due to the possibility of intermittent epidemics (22 types) | Malaria, tuberculosis, leprosy, scarlatina, meningococcal meningitis, legionnaires’ disease, vibrio vulnificus septicemia, epidemic typhus, murine typhus, tsutsugamushi disease, leptospirosis, brucellosis, anthrax, rabies, hemorrhagic fever with renal syndrome (HFRS), influenza, Acquired Immune Deficiency Syndrome (AIDS), syphilis, Creutzfeldt-Jakob disease (CJD), variant Creutzfeldt-Jakob disease (vCJD), hepatitis C, vancomycin-resistant Staphylococcus aureus (VRSA) infection, Carbapenem-resistant Enterobacteriaceae (CRE) infection |
| Group 4 | Concerns regarding new domestic emergence or overseas inflows (20 types) | Plague, yellow fever, dengue, viral hemorrhagic fevers (Marburg fever, Lassa fever, Ebolavirus disease), smallpox, botulism, severe acute respiratory syndrome (SARS), Avian Influenza A (H7N9) virus infection, Influenza A/H1N1, tularemia, query fever, West Nile fever, EID syndrome, Lyme disease, tick-borne encephalitis, melioidosis, chikungunya fever, severe fever with thrombocytopenia syndrome (SFTS), Middle East respiratory syndrome (MERS), Zika virus infection |
| Group 5 | Routine check-up for parasitic infectious diseases (6 types) Designated | Ascariasis, trichuriasis, oxyuriasis, clonorchiasis, paragonimiasis, intestinal trematodes |
| Designated | Investigation and monitoring of epidemics (14 types) | Hand, foot, and mouth disease, gonorrhea, Chlamydia infection, chancroid, genital herpes, condylomacuminatea, vancomycin-resistant enterococci (VRE) infection, methicillin-resistant Staphylococcus aureus (MRSA) infection, multidrug-resistant pseudomonas aeruginosa (MRPA) infection, Multi-resistant Acinetobacter (MRAB) infection, gastrointestinal infections, acute respiratory infections, imported parasite infections, enterovirus infection |

Source: Ministry of Health and Welfare (2017). Infectious Disease Control and Prevention Act.
determined. For model 1 and model 3, the spatial lag model was more suitable, and the spatial error model was more suitable for model 2, model 4, and model 5.

Table 6 shows the estimation results of each model using the spatial regression model. In model 1, targeting all EID, the variable of low education level was positive and high, and the EID was high in good-quality residential environments with a high economic level of the local government. EID was high in areas where the number of residents per civil servant is high, which means that infectious diseases are high in areas where there are many targets to be managed by the government. The spatial relationship with the surrounding area was positively 0.126.

In model 2, targeting Group 1 infectious diseases, the spatial dependence of the error term was found to have a positive relationship. The outbreak of Group 1 infectious diseases showed a positive relationship with the characteristics of low socioeconomic status, which was related to the nature of infectious diseases caused by water or food. In addition, there is a positive relationship in regions with a high economic level of the local government, which can be understood as indicating that socioeconomically vulnerable groups existing in relatively wealthy regions have a substantial relationship with the outbreak of Group 1 infectious diseases. With regard to environmental factors, mild weather and precipitation showed a positive relationship with the EID of Group 1.

In model 3, targeting Group 2 infectious diseases, there was a higher ratio to those with an education level below elementary school graduate. In addition, there was a negative relationship with semi-basement households and a positive relationship with a high economic level of the local government, which can be understood as showing that the group with a low education level has a relationship with the outbreak of Group 2 infectious diseases in a good residential environment. As the characteristics of the EID of Group 2 are related to vaccination, these diseases had the highest positive relationship with the number of residents per civil servant compared to other models. Regarding environmental factors, mild weather and precipitation showed a positive relationship with the EID of Group 2 infectious diseases, and the degree was higher than that of Group 1 infectious diseases. The spatial relationship with the surrounding area was positively 0.145.

In model 4, targeting Group 3 infectious diseases, the spatial dependence of the error term was found to have a positive relationship. Infectious diseases in Group 3 were found to be high in areas with good environmental conditions such as clean water and good sanitation. The outbreak of Group 3 infectious diseases showed a positive relationship with the characteristics of low socioeconomic status, which was related to the nature of infectious diseases caused by food or water. In addition, there is a positive relationship in regions with a high economic level of the local government, which can be understood as indicating that socioeconomically vulnerable groups existing in relatively wealthy regions have a substantial relationship with the outbreak of Group 3 infectious diseases. With regard to environmental factors, mild weather and precipitation showed a positive relationship with the EID of Group 3.

In model 5, targeting Group 4 infectious diseases, the spatial dependence of the error term was found to have a positive relationship. Infectious diseases in Group 4 were found to be high in areas with good environmental conditions such as clean water and good sanitation. The outbreak of Group 4 infectious diseases showed a positive relationship with the characteristics of low socioeconomic status, which was related to the nature of infectious diseases caused by food or water. In addition, there is a positive relationship in regions with a high economic level of the local government, which can be understood as indicating that socioeconomically vulnerable groups existing in relatively wealthy regions have a substantial relationship with the outbreak of Group 4 infectious diseases.
In order to determine how urban characteristics relate to infectious diseases, the sum of EID of all groups was defined as model 1, and four infectious disease groups were defined from models 2–5; the spatial regression model was then applied. The validity of the spatial regression model existed for all the models. The urban characteristics were shown to have different influences for each infectious disease group. The EID of Group 1 and Group 2 were highly related to the characteristics of low socio-economic status, and common environmental factors were the number of days above 25 °C degrees and precipitation. The characteristics of vulnerable groups are important because the infectious diseases in Groups 1 and 2 have water or food-mediated characteristics or are infectious diseases targeted for vaccination. Group 3 infectious diseases with intermittent epidemic potential were related to good residential environments and were highly related to the number of residents per civil servant, which is related to the regional response capacity of the local government. New infectious diseases, Group 4 infectious diseases, showed positive and high spatial effects compared to other infectious diseases. Among the environmental factors, these diseases were negatively related to a high temperature environment, mild weather, and precipitation. Model 5 had a lower explanatory power than did the other models; it was understood to have a different EID system from the infectious diseases in Groups 1–3.

This study investigated the relationship between urban characteristics and the emergence of infectious diseases. The urban characteristics associated with infectious diseases can be divided into two categories (Reyes, Ahn, Thurber, & Burke, 2013), static and dynamic. Dynamic characteristics include urban connectivity and human migration and are related to the influx and spread of infectious diseases from the outside (Jones et al., 2017). Static characteristics have formed over a long time, are resistant to change, and include a region’s population, socioeconomic level, educational level, infrastructure, and degree of urbanization (McMichael, 2004). These statistical properties are directly or indirectly related to the emergence of infectious diseases (McMichael, 2004; Semenza et al., 2013).

The results of this study showed that the static characteristics of the host and environmental factors of infectious diseases among urban characteristics are related to the emergence of infectious diseases. This carries implications for urban planning and policies required to make a city resilient against external threats. Urban resilience undergoes a process of gradual transformation (Kim & Lim, 2016). In terms of resilience, it is necessary to improve the factors related to static characteristics for the city to improve as it recovers from the emergence of infectious diseases.

The re-emergence of existing infectious diseases due to climate and environmental changes as well as the emergence of new infectious diseases poses a problem to society (Santos-Vega et al., 2016; Tong et al., 2015; Wilcox & Colwell, 2005). The belief that infectious diseases can be controlled through the invention of vaccines has appeared in the field of urban planning, and recent urban planning tends to overlook the problems of infectious diseases and sanitation that were originally addressed (Matthew & McDonald, 2006; Neiderud, 2015; Tong et al., 2015). Recently, however, infectious diseases such as MERS, SARS, Influenza A virus subtype H1N1, and COVID-19 have become worldwide epidemics (World Health Organization, 2005, 2014). Moreover, the appearance of new vectors or changes to vector behavior due to climate change increase the risk of re-emergence and spread of existing infectious diseases (Neiderud, 2015; Tong et al., 2015). Such risk of infectious disease is an issue troubling not only developing regions, but also developed regions (Neiderud, 2015).

In particular, COVID-19 has affected people’s behavior, lifestyle, and social relations, especially in urban areas. According to the results of
required to ascertain the relationship between the weather condition and the COVID-19 outbreak, but the descriptive pattern of this study can induce inter-city governance and cooperative regional approach to urban planning (Matthew & McDonald, 2006). The result of this study can be considered to ascertain the relationship between the weather condition and COVID-19 by applying a spatial model targeting the COVID-19 outbreak.

This study concludes that the relationship between EID and urban characteristics is different for each type of infectious disease and spatial characteristic. This requires new research and discussions on how people’s behavior, urban lifestyle, and social relations have a certain spatial range when considering infectious diseases in cities. Making a city resilient from the risk of infectious disease requires a fundamental behavior, urban lifestyle, and social relations have a certain spatial range when considering infectious diseases in cities. Making a city resilient from the risk of infectious disease requires a fundamental approach to urban planning (Matthew & McDonald, 2006). The result of this study can induce inter-city governance and cooperative regional planning to resolve infectious diseases, especially given that urban characteristics continuously form spatial clusters and the emergence of infectious diseases is connected to urban planning.

Table 5
Linear Model with Ordinary Least Squares.

| Variable  | Model 1 (Dependent Variable: Total) | Model 2 (Dependent Variable: G1) | Model 3 (Dependent Variable: G2) | Model 4 (Dependent Variable: G3) | Model 5 (Dependent Variable: G4) |
|-----------|------------------------------------|-----------------------------------|----------------------------------|----------------------------------|----------------------------------|
|           | Coefficient | s.e | Coefficient | s.e | Coefficient | s.e | Coefficient | s.e | Coefficient | s.e |
| Constant  | -1899.2*** | 593.34 | -112.799*** | 26.36 | -1299.53*** | 442.05 | -509.906*** | 195.24 | -6.973* | 3.907 |
| H3        | 0.071*** | 0.01 | 0.003*** | 0.00 | 0.049*** | 0.08 | 0.020*** | 0.003 | 0.000*** | 0.00 |
| H4        | -78.146*** | 16.265 | 1.572*** | 0.723 | -56.084*** | 12.118 | -23.743*** | 5.352 | 0.108 | 0.107 |
| H5        | 24.655** | 12.186 | 1.672*** | 0.541 | 14.468 | 9.079 | 8.529*** | 4.010 | -0.014 | 0.080 |
| E2        | -5.443 | 5.407 | 0.089 | 0.240 | -4.131 | 4.029 | -1.372 | 1.779 | -0.028 | 0.036 |
| E4        | 23.288*** | 3.977 | 1.193*** | 0.177 | 23.909*** | 2.963 | 8.020*** | 1.309 | 0.098*** | 0.026 |
| E5        | 2.310*** | 0.375 | 0.114*** | 0.017 | 1.691*** | 0.279 | 0.505*** | 0.123 | 0.000 | 0.002 |
| E6        | -0.041 | 10.472 | 0.232 | 0.465 | -0.420 | 7.802 | 0.045 | 3.446 | 0.103 | 0.069 |
| E7        | -23.389 | 16.399 | -1.757*** | 0.729 | -21.348* | 12.218 | 0.202 | 5.396 | -0.486*** | 0.108 |
| E8        | 15.255*** | 7.430 | 0.513 | 0.330 | 11.924*** | 5.536 | 2.621 | 2.445 | 0.198*** | 0.049 |
| E9        | 233.547*** | 36.646 | 11.941*** | 1.628 | 143.784*** | 27.302 | 76.584*** | 12.059 | 1.241*** | 0.241 |

NOTE: ***p < 0.01, **p < 0.05, *p < 0.1.

Table 6
Spatial Regression Model.

| Variable  | Model 1 (Dependent Variable: Total) | Model 2 (Dependent Variable: G1) | Model 3 (Dependent Variable: G2) | Model 4 (Dependent Variable: G3) | Model 5 (Dependent Variable: G4) |
|-----------|------------------------------------|-----------------------------------|----------------------------------|----------------------------------|----------------------------------|
|           | Coefficient | s.e | Coefficient | s.e | Coefficient | s.e | Coefficient | s.e | Coefficient | s.e |
| Constant  | -2021.2*** | 583.508 | -63.373*** | 24.014 | -1363.89*** | 432.4 | -380.280* | 195.695 | -7.581* | 3.940 |
| H3        | 0.076*** | 0.01 | 0.002*** | 0.00 | 0.052*** | 0.008 | 0.020*** | 0.003 | 0.000*** | 0.00 |
| H4        | -77.862*** | 15.754 | 1.539*** | 0.811 | -55.747*** | 11.685 | -20.489*** | 5.748 | 0.077 | 0.118 |
| H5        | 25.974** | 11.940 | 1.606 | 0.496 | 15.722** | 8.871 | 4.847 | 4.029 | 0.034 | 0.081 |
| E2        | -4.889 | 5.225 | -0.055 | 0.195 | -3.769 | 3.882 | -1.060 | 1.696 | -0.020 | 0.034 |
| E4        | 30.717*** | 3.930 | 0.772*** | 0.173 | 21.941*** | 2.918 | 7.038*** | 1.343 | 0.166*** | 0.027 |
| E5        | 2.084*** | 0.372 | 0.095*** | 0.016 | 1.510*** | 0.277 | 0.434*** | 0.127 | 0.003 | 0.003 |
| E6        | 1.830 | 10.146 | -0.205 | 0.418 | 1.143 | 7.535 | -0.344 | 3.447 | 0.065 | 0.069 |
| E7        | -20.992 | 15.879 | -0.562 | 0.947 | -18.680 | 11.807 | -2.319 | 6.233 | -0.526*** | 0.130 |
| E8        | 12.995*** | 7.273 | 0.823*** | 0.433 | 9.727*** | 5.422 | 2.507 | 2.802 | 0.248*** | 0.058 |
| E9        | 228.252*** | 35.400 | 12.560*** | 1.867 | 138.988*** | 26.292 | 78.128*** | 13.024 | 1.273*** | 0.268 |
| p         | 0.126** | 0.064 | 0.609*** | 0.067 | 0.145** | 0.066 | 0.3*** | 0.091 | 0.355*** | 0.088 |

NOTE: ***p < 0.01, **p < 0.05, *p < 0.1.

group 4 (model 5) of this study, which relates to a new infectious disease such as COVID-19, weather-related factors were found to have more influence than other existing factors that affect the spread of infectious diseases. In line with this finding, some recent studies, though with mixed results (Qi et al., 2020), reveal that high temperature and high humidity are related to the spread of COVID-19 (Paez, Lopez, Menezes, Cavalcanti, & Da Rocha Pitta, 2020; Wang et al., 2020), and others reveal that high temperature and low humidity are related to the spread of COVID-19 (Byass, 2020). However, despite these recent results, the spatial relationship between the weather condition and COVID-19 outbreak, but the descriptive pattern of this relationship has not been researched. Therefore, further research is required to ascertain the relationship between the weather condition and COVID-19 by applying a spatial model targeting the COVID-19 outbreak.
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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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None.

Appendix A. Data Sources

| Measurement variable                  | Data Source                                                                 | Access                                      |
|--------------------------------------|-----------------------------------------------------------------------------|---------------------------------------------|
| Infectious disease                   | Korean city statistics (Ministry of the Interior and Safety)                | Official Website (http://kosis.kr)          |
| Elderly population (H1)              | Population and housing census                                              | Official Website (http://kosis.kr)          |
| Infant population (H2)               | Population and housing census                                              | Official Website (http://kosis.kr)          |
| Number of national basic living security recipients (H3) | Statistical year book of local governments               | Official Website (http://kosis.kr)          |
| Ratio of semi-base ment households (H4) | Population and housing census                                              | Official Website (http://kosis.kr)          |
| Ratio of population with a maximum of elementary school graduation (H5) | Population and housing census                                              | Official Website (http://kosis.kr)          |
| Impervious area ratio (E1)           | Land cover map (Ministry of Environment)                                   | Official Website (http://egis.me.go.kr)     |
| Number of disaster risk facilities with a grade of D or lower (E2) | Statistical yearbook on natural disasters (Ministry of Public Safety and Security) | (https://www.mois.go.kr/rkt/bbs/type001/commonSelectBoardList.do?bbsId=BSBMSTR_00000000132) |
| Population density (E3)              | Population and housing census                                              | Official Website (http://kosis.kr)          |
| Financial independence ratio (E4)    | Statistical yearbook of local governments                                 | Official Website (http://kosis.kr)          |
| Number of residents per civil servant (E5) | Statistical yearbook of local governments                                 | Official Website (http://kosis.kr)          |
| Social organization participation rate (E6) | Population and housing census                                              | Official Website (http://kosis.kr)          |
| Days with highest average daily temperature no less than 33°C between 2000-2010 (E7) | Korea Meteorological Administration (2012)                            | Official Website (http://www.korea.go.kr/home/) |
| Days with lowest average daily temperature no less than 25°C between 2000-2010 (E8) | Korea Meteorological Administration (2012)                            | Official Website (http://www.korea.go.kr/home/) |
| Days with average daily precipitation no less than 80 mm between 2010-2010 (E9) | Korea Meteorological Administration (2012)                            | Official Website (http://www.korea.go.kr/home/) |

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