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Examining the Association between Socioeconomic Status and Exposure to Carcinogenic Emissions in Gyeonggi of South Korea: A Multi-Level Analysis

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Abstract: Although South Korea introduced the Pollutant Release and Transfer Register system in 1996, there is relatively limited evidence on how socioeconomic status at both individual and municipal levels is associated with exposure to toxic chemicals in Korea because of limited data sources. Using a multi-level negative binomial model, this study examined the socioeconomic status of both individuals and municipalities with a higher level of exposure to carcinogenic emissions from industrial facilities in Gyeonggi province, South Korea. The results reveal that economic minority individuals (national basic livelihood security recipients, unemployed people, and tenants), municipalities with higher percentages of industrial land use, and foreign-born populations had more facilities that produce carcinogenic emissions. While similar findings have been reported by many environmental justice studies conducted in other countries, this is the first Korean case study that reports the relationship between socioeconomic status at both individual and municipal levels and exposure to toxic chemicals.

Keywords: environmental justice; socioeconomic status; exposure to toxic chemicals; carcinogens; pollutant release and transfer register; multi-level negative binomial model; spatial analysis; Korea

1. Introduction

The sociologist Ulrich Beck [1] originally stated that "poverty is hierarchic, while smog is democratic" (p.32). This means that, with the expansion of risks affecting the environment and the human health, social differences and limitations are relativized, and thus the risks equally apply to everyone [1]. However, it is not the case that all people are affected by or exposed to environmental risks at the same level [2]. Many environmental justice studies have empirically showed that people with different socioeconomic status (SES), such as race, income, and educational attainment, are exposed to and thus affected by risks at various levels [3–9]. In other words, the SES determines the likelihood of people to be exposed to or prevent risks [10]. Therefore, environmental risks are, in fact, distributed inequitably among people. As a result, Ulrich Beck has changed his position that emphasized the universality of environmental risks to a new one emphasizing the inequitable distribution of environmental risks [11,12].

Many existing environmental justice studies are originated in the United States and have focused on inequitable exposure to toxic chemicals released from industrial facilities using the data from the Toxic Release Inventory (TRI), which provides extensive information on toxic chemicals. A toxic chemical leakage accident at the Union Carbide chemical plant in Bhopal, India in 1984 killed an estimated 20,000 people and a toxic outflow at another Union Carbide facility in West Virginia in 1985 injured over 100 people. Experiencing these two back-to-back disasters and thereafter recognizing the danger of toxic chemicals, the United States government has provided communities with information on the amount of emissions and the transfer of toxic chemicals in their regions through the TRI system since 1987 [13]. The data in the TRI are used in many studies on exposure to toxic chemicals focusing on vulnerable populations [14–22].

While early studies on inequitable exposure to toxic chemicals focused on racial and ethnic minorities, recent studies around the world have expanded their interests to other SES factors including income, poverty, employment status, educational attainment, biological minorities, homeownership, housing price, and political participation [3,10,23–27]. Although many studies have established the relation between low SES and high exposure to toxic chemicals, some studies report no statistically significant relationships between SES and exposure [28–30]. Particularly, studies in the United States, Asia, and Africa show that populations with lower SES are more likely to be exposed to toxic air pollutants, whereas the European studies show mixed results [31].

South Korea first introduced the Pollutant Release and Transfer Register (PRTR) system in 1996, similar to the U.S. TRI, when it joined the Organization for Economic Co-operation and Development. However, there have been few studies on characterizing the populations living in proximity to industrial polluters. Recently, Yoon et al. [32] investigated environmental inequality in South Korea using PRTR data. Employing a spatial regression model, they found that the distribution of facilities in South Korea that release toxic emissions are inequitably distributed in areas with a high proportion of minorities, weaker political activity, excessive industrial land use, and less commercial land use [32]. However, this study used aggregated data at the municipal level because of the limitations of data sources.

Because SES is typically characterized using aggregated data at the regional level in many environmental justice studies, there is relatively limited evidence on how individual level SES factors are associated with exposure to toxic chemicals. SES data aggregated at the regional-level are relatively easy to acquire from public sources, although the individual level SES factors are more difficult to obtain [23,33]. Moreover, recent environmental inequity studies have emphasized importance of considering SES at both individual and regional levels [27,31,33]. The use of these multi-level data requires a more complex statistical approach, such as multi-level modeling, than the Ordinary Least Square model typically used in previous studies [33,34].

More generally, the association between SES and inequitable exposure to toxic chemicals still needs to be investigated in Korea. This study aimed to examine the SES characteristics of both individuals and municipalities with a higher level of exposure to carcinogenic facilities from an environmental justice perspective in Gyeonggi province, South Korea. While the toxic chemical data (particularly, carcinogens) were taken from the PRTR for the period 2013–2015, the individual level SES factors were obtained from the 2016 "Survey on the quality of life of Gyeonggi-do residents". The survey provides 124 SES factors on households, family relations, residence, family budget, employment, transportation, environment, social integration, and well-being of a sample of 20,000 households in Gyeonggi. Unlike the previous studies conducted in Korea, this research considered a wider variety of SES factors and usec multi-level SES factors estimated at both the individual and municipal levels. To our knowledge, this is the first research in Korea showing how exposure to carcinogenic emissions is inequitably distributed among individuals and municipalities with different SES in Gyeonggi.

2. Materials and Method

2.1. Study Area

Gyeonggi Province was selected as the study area. The region has the highest population among the 17 provinces of South Korea (12.7 million residents in 2016). Although the geographical area of the province accounts for only 10% of the nation's total land area, approximately a quarter of

Korea's population (51.7 million) lives in Gyeonggi. The province is composed of 31 municipal-level divisions (si-gun) and 553 submunicipal-level divisions (eup-myeon-dong, EMD). Gyeonggi has several big cities with more than one million inhabitants such as Suwon and Goyang in addition to many small- and medium-sized cities and small rural areas. Gyeonggi is an industrial province with the highest emissions in the country. According to the 2016 data of the Korea National Statistical Office, 126,000 manufacturing firms in Gyeonggi account for 30.2% of the total number of manufacturing firms in the country [35]. In 2015, 21.5% of the total nationwide emissions were released in Gyeonggi [36].

2.2. Data

This study relied on two main data sources. The PRTR data were provided by the National Institute of Chemical Safety, the Korea Ministry of Environment's affiliated organization. Although information on the release and transfer of 415 types of toxic chemicals is available, unlike the TRI, Korea's PRTR does not provide information on the toxicity of each individual chemical; only the total amount of each chemical released is available [37,38]. Therefore, this study focused on carcinogens (including 1, 2A, and 2B groups), whose impacts on the human body are considered more direct than other hazardous chemicals. PRTR data can be extracted by year, region, chemical, industry, and facility. This study used the facility unit dataset from 2013 to 2015 because street addresses of each facility are available only in this dataset. Using the address information, it is possible to geocode the locations of toxic release facilities using Geographic Information Systems (GIS) for spatial analysis. Between 2013 and 2015, 276 carcinogen-releasing facilities were present in Gyeonggi and they emitted 626.5 ton of carcinogens annually. These facilities are unevenly distributed in the region (see Figure 1). They are mainly concentrated in the southwestern part of the province where traditional manufacturing industries are concentrated.

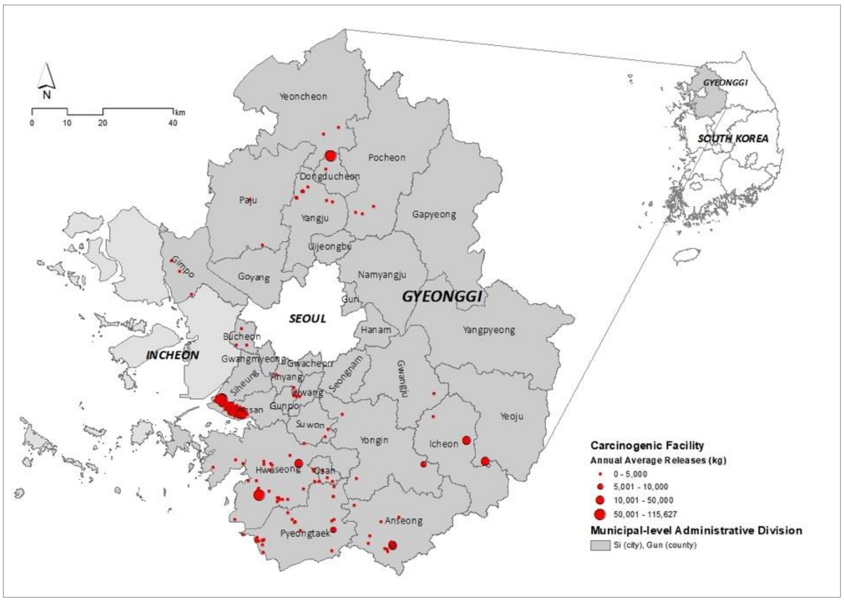

Figure 1. Location of facilities that produce carcinogenic emissions in Gyeonggi.

The second dataset used in this study is from the "Survey on the quality of life of residents in Gyeonggi". The survey was conducted by the Gyeonggi Research Institute in 2016 to measure the quality of life of Gyeonggi's residents. This dataset provides individual level microdata based on the answers to a total of 124 questions on the household information, family relations, residence, family budget, employment, transportation, environment, social integration, and well-being of a sample of 20,000 households. The dataset includes not only household- but also individual-level information. While most previous Korean studies have used aggregated data at the regional level and considered limited socioeconomic factors, this dataset provides a unique opportunity to investigate a wide variety of individual level SES factors responsible for unequal exposure to carcinogens.

3. Methods

3.1. Spatial Assessment of Facilities that Produce Carcinogenic Emissions

Most studies on the inequitable distribution of toxic releases in Korea have relied on the administrative division-based approach, which sums up the number of facilities and the amount of toxins in each administrative boundary. This approach is relatively simple because aggregated data at the administrative division-level are readily available; however, it may raise modifiable area unit problems, in which the analysis results vary with the spatial unit [39,40]. As shown in the map on the left in Figure 2, calculation results regarding the toxic release facilities vary significantly with the administrative level selected by the researcher. In addition, since this approach ignores the fact that toxic pollutants diffuse over administrative boundaries, facilities located near residences at the edge of the boundaries are likely to be excluded, depending on the size and shape of the administrative boundary.

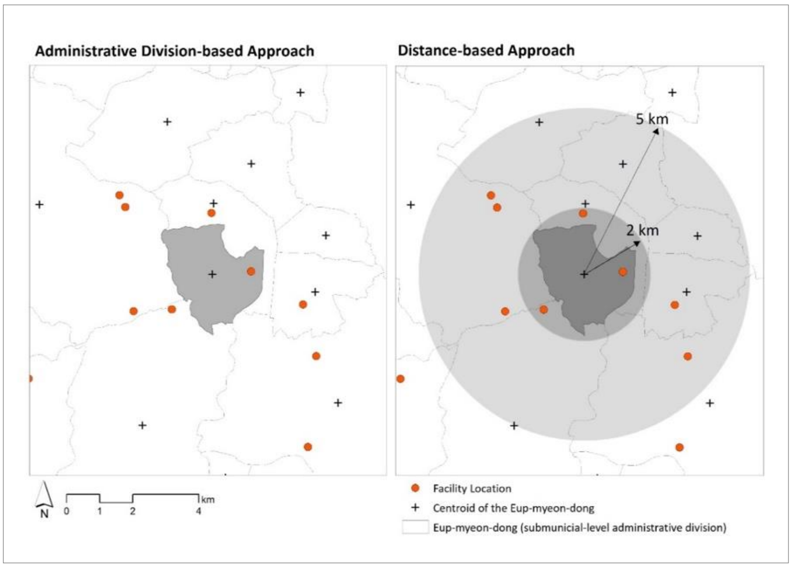

Figure 2. Spatial assessment of facilities that produce carcinogenic emissions: administrative division-based versus distance-based approach.

To overcome these problems, this study applied the distance-based approach. Using proximity analysis in GIS, we calculated the number of facilities that produce carcinogenic emissions within a certain distance from the place of residence. While the facilities can be geocoded using their street addresses, the "Survey on the quality of life of residents in Gyeonggi" does not provide information on the address of 20,000 individuals to protect their privacy. Instead, the centroid of each EMD, the smallest administrative division unit, was assumed as the place of residence. The range of direct influence of carcinogens was set to 2 km because after two cases of hydrofluoric acid leakage occurred in Korea in 2012 and 2013, hydrofluoric acid was detected within a radius of 2 km from the location of the accident. In 2012 in the City of Gumi, South Korea, there was a hydrofluoric acid leakage accident at a chemical plant where five were killed and 18 were injured. In January 2013, Samsung electronics facilities in the City of Hwaseong, Gyeonggi also experienced hydrofluoric acid leakage, resulting in one death and four injuries. During the 2012 accident, ginkgo tree leaves within a radius of 2 km wilted; additionally, hydrofluoric acid was detected in plants within a 2 km radius in the 2013 accident. The range of indirect influence of carcinogens was set to 5 km because the distance of the diffusion of chemicals due to winds is normally 4–5 km [41,42]. The map on the right in Figure 2 shows the industrial facilities within 2 and 5 km of the centroid of the EMD.

3.2. Examining SES Factors Associated with Exposure to Carcinogenic Emissions from Industrial Facilities

We used a multi-level model to investigate how the SES evaluated at both individual and municipal levels was associated with exposure to carcinogenic emissions from industrial facilities. The multi-level model is an appropriate analytical technique for estimating the degree to which the effects of independent variables at lower levels (e.g., individual, household, and firm) on dependent variables are mediated by contextual factors at higher levels (e.g., neighborhood, municipality, and region) [34,43]. The dependent variables are the number of facilities within 2 and 5 km. Because the nature of the dependent variable such as the number of facilities is that of counts, the appropriate choice for modeling are Poisson and negative binomial distributions. Since the Poisson distribution is restricted in that its mean and variance are equal, a negative binomial model was used to relax the restriction. A multilevel negative binomial model was used to examine the association between SES at two different levels and exposure to carcinogenic facilities. This analysis was conducted with the Stata/MP 15 software.

The independent variables were considered at two different levels. First, the individual level variables were selected from the "Survey on the quality of life of residents in Gyeonggi". These variables include age, gender, number of children (household members aged under 15), number of elderly people (household members aged 65 or above), educational attainment, average monthly household income, national basic livelihood security recipients, work status and housing tenure, which represent the SES of the individuals. Additionally, this study used aggregated data at the municipal-level divisions (si-gun) to characterize those SES factors. These data included population density, population of foreign-born individuals, and industrial land use, and were provided by the Statistics Korea office. Table 1 shows the descriptive statistics for all variables.

Table 1. Descriptive statistics.

	Variable		Mean/Freq.	SD/Percent
Dependent variable	Facility count (2 km)		0.6	4.4
	Facility count (5 km)		3.1	12.7
Independent variable	Individual level (Level 1)			
	Age	Age	51.3	14.3
		Age^2	2834.0	1519.5
	Gender	Male	16,903	84.5
		Female	3097	15.5
	Number of children under 15		0.4	0.7
	Number of elderly, i.e., 65 or above		0.4	0.7
	Education attainment	Middle school or less	2403	12.0
		High school	8127	40.6
		College	4060	20.3
		Bachelor	5106	25.5
		Graduate or above	304	1.5
	Household income	First quartile	5185	25.9
		Second quartile	4929	24.6
		Third Quartile	4992	25.0
		Fourth Quartile	4894	24.5
	National basic livelihood security	Non-recipient	19,667	98.3
		Recipient	333	1.7
	Employment status	Employed	16,968	84.8
		Unemployed	314	1.6
		Inactive	2718	13.6

Table 1. *Cont.*

Variable		Mean/Freq.	SD/Percent
Work status	Self-employed	3932	19.7
	Regular	12,609	63.1
	Temporary	329	1.7
	Unpaid family worker	98	0.5
Housing tenure	Owner-occupied	11,831	59.2
	Rental	7983	39.9
Municipal level (Level 2)			
Population density (person/km^2)		3290	3714
Percentage of industrial land use		2.1	2.7
Percentage of foreign-born residents		3.6	2.4

Note Number of observations (individual) = 20,000, Number of groups (municipalities) = 31. Mean and standard deviation reported for continuous variables, and frequency and percentage reported for categorical variables.

4. Results and Discussion

4.1. Spatial Patterns of Facilities that Produce Carcinogenic Emissions

In Figure 3, the upper maps show the results of the spatial analysis that calculated the number of facilities within 2 and 5 km of the centroid of EMDs. The number of EMDs where at least one facility is located within 2 km is 97 (17.5% of the total of 553 EMDs). These areas are mainly concentrated in southwestern Gyeonggi. Particularly, there are several EMDs in Siheung and Ansan containing more than 10 facilities within 2 km of their centroids. In contrast, except for some areas, there are only a few facilities releasing carcinogens in eastern and northern Gyeonggi. The number of areas affected by the release of carcinogens increases significantly when the radius is expanded to 5 km. The number of EMDs with at least one facility within 5 km is 250 (45.2% of the total). These facilities are located in southwestern, northern, and southeastern Gyeonggi.

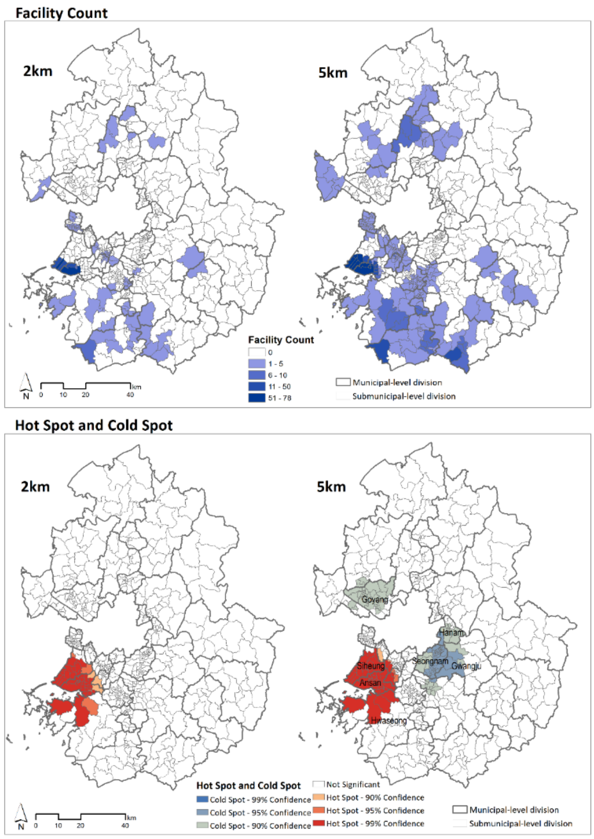

Figure 3. Spatial patterns of facilities that produce carcinogenic emissions.

The lower maps in Figure 3 represent the results of hotspot analysis conducted in GIS. Hotspot analysis is an effective tool for identifying spatial clusters of areas with either high or low numbers of carcinogenic facilities across EMDs [44]. As depicted in the lower-left (2 km) map in Figure 3, Siheung, Ansan, and northern parts of Hwaseong are hot spots for facilities that produce carcinogenic emissions. Whereas the hot spots areas expand in the lower-right (5 km) map, some areas in Gyeonggi such as Seongnam, Hanam, northwestern parts of Gwangju, and Goyang were determined to be cold spots, with low numbers of facilities.

4.2. SES Factors Associated with Exposure to Carcinogenic Emissions from Industrial Facilities

Table 2 represents the estimated results of our analyses for SES factors at both individual and municipal levels associated with proximity to facilities that produce carcinogenic emissions. Columns 1 and 2 of Table 2 show the estimated results of multi-level negative binomial regression models. The dependent variables in each model are the number of facilities within 2 and 5 km.

Table 2. SES factors associated with proximity to facilities that produce carcinogenic emissions.

		2 km Distance Model		**5 km Distance Model**	
Individual level (Level 1)					
Age	Ln (Age)	0.018	(1.319)	0.004	(0.654)
	Ln (Age^2)	−0.000	(−1.466)	−0.000	(−0.803)
Gender	Male (ref.)				
	Female	0.089	(1.443)	0.034	(1.095)
Number of children under 15		0.054	(1.490)	0.018	(0.952)
Number of elderly, i.e., 65 or above		0.003	(0.050)	−0.030	(−1.108)
Education attainment	Middle school or less (ref.)				
	High school	0.007	(0.081)	−0.068	(−1.606)
	College	−0.017	(−0.167)	−0.021	(−0.401)
	Bachelor	0.060	(0.585)	−0.003	(−0.066)
	Graduate or above	0.412 **	(2.198)	0.086	(0.877)
Household income	First quartile (ref.)				
	Second quartile	0.110	(1.526)	0.062 *	(1.759)
	Third Quartile	0.094	(1.236)	0.032	(0.870)
	Fourth Quartile	0.357 ***	(4.679)	0.163 ***	(4.337)
National basic livelihood security	Non-recipient (ref.)				
	Recipient	0.209	(1.224)	0.306 ***	(3.679)
Employment status	Employed (ref.)				
	Unemployed	0.075	(0.410)	0.168 *	(1.888)
	Inactive	0.283 ***	(2.802)	0.064	(1.292)
Work status	Self-employed (ref.)				
	Regular	0.079	(1.235)	0.080 **	(2.516)
	Temporary	0.075	(0.414)	−0.078	(−0.868)
	Unpaid family worker	−0.403	(−1.140)	−0.557 ***	(−3.225)
Housing tenure	Owner-occupied (ref.)				
	Rental	0.142 ***	(2.591)	0.061**	(2.221)
	Other	−0.388	(−1.325)	−0.458 ***	(−3.143)
Municipal level (Level 2)					
Population density		−0.000	(−0.868)	−0.000	(−0.195)
Percentage of industrial land use		1.009 ***	(3.430)	0.695 ***	(2.599)
Percentage of foreign-born residents		0.571 **	(2.027)	0.568 **	(2.225)
Cons		−8.510 ***	(−6.551)	−5.291 ***	(−4.921)
Model Summary					
Number of observations		20,000		20,000	
Number of group		31		31	
AIC		22,756.66		52,258.74	
BIC		23,001.67		52,503.75	

Note. t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Among the individual level SES factors, the variables of education attainment, household income, national basic livelihood security recipients, employment status, work status, and housing tenure are statistically significant. The increasing average monthly household income had a negative impact on the exposure to carcinogenic facilities. However, the coefficient of the “national basic livelihood security recipients" factor had a statistically significant positive sign in the 5 km distance model. This means that the national basic livelihood security recipients who receive government support for living, medical care, housing, and education expenses owing to their economically difficult conditions are more often exposed to facilities that produce carcinogenic emissions. Many poor people live in polluted areas because the land price in those areas is lower [14,45], creating the problem of environmental inequity due to the spatial proximity of toxic facilities to areas where the economically disadvantaged people reside.

Employment and work status were found to be related to the level of exposure to carcinogens. The 5 km distance model shows that the level of exposure to carcinogens is higher for unemployed people than that for employed people. This finding is similar to the results of some previous studies conducted in other countries [6,10]. In addition, the 2 km distance model revealed that the exposure level is higher in economically inactive people than in employed people. In terms of work status, the exposure of regular workers is higher than those of self-employed people in the 5 km distance model. In contrast, unpaid family workers are less likely to be exposed to carcinogens compared to self-employed people in the 5 km distance model. Housing tenure is also associated with the exposure level to carcinogens. In both 2 km and 5 km models, the coefficients of rental had a statistically significant positive sign. This means that renters are more exposed to carcinogens than homeowners.

In summary, facilities that produce carcinogenic emissions in Gyeonggi are inequitably distributed in regard to economic minority individuals (national basic livelihood security recipients, unemployed people, and tenants) but not in regard to gender and biological minorities (children and elderly) at the individual level. While this finding is consistent with the results of some previous studies conducted in other countries [6,10], this study is the first one to report the relationship between individuals with low SES and high exposure to toxic chemicals in Korea.

A previous study in Korea argues that there is no significant relationship between the economic status and the exposure to toxic substances (including carcinogens) that are released by industrial facilities [32]. Because the authors used data aggregated at the municipal level, they had limited ability to identify the economic characteristics at both individual and municipal levels. In contrast, our study confirmed that individuals with low economic status have greater exposure to carcinogenic emissions from industrial facilities.

Our results also indicate that municipalities with low SES have more facilities that produce carcinogenic emissions. The coefficients of the foreign-born population and industrial land use had a statistically significant positive sign in all models, whereas those of population density were statistically insignificant. Living in a municipality with a higher industrial land use rate was associated with higher exposure to carcinogens. As shown in Figure 3, the facilities that produce carcinogenic emissions are mainly concentrated in southwestern Gyeonggi, where several industrial parks are located and there is a higher rate of industrial land use. These industrial sites have negative impact in regard to exposure to carcinogens for residents in those areas.

In addition, a higher rate of foreign-born individuals in the population was linked to increased exposure to carcinogens. Most of the foreign-born population in Gyeonggi is composed of migrant workers who are mainly engaged in manufacturing sector [46]. Several studies on foreign migration workers in Korea have suggested that they are exposed to low wages, poor working conditions, and risks as low-skilled workers [47,48]. Furthermore, most tend to live near their workplace to limit living costs [47]. This suggests that the foreign-born residents (mainly migrant workers and their family members) in Gyeonggi might be suffering from double exposure to toxic chemicals: both at their work and at home.

5. Conclusions

This study empirically analyzed how facilities that produce carcinogenic emissions are inequitably distributed among individuals and municipalities with different SES in Gyeonggi, South Korea. There is limited previous evidence for how individual level SES factors are associated with exposure to toxic chemicals in Korea because most studies use data aggregated at the regional level. In contrast, by using the multi-level model, our study considered a wider variety of SES factors and used multi-level SES factors estimated both at the individual and municipal levels.

This study confirmed that the individuals and municipalities with low SES in Gyeonggi are associated with high exposure to facilities that produce carcinogenic emissions. For SES factors at the individual level, our results indicate that poverty, unemployment, and renting a house are associated with higher exposure to carcinogens. National basic livelihood security recipients, which represent the poorest of the poor, have a higher level of exposure than non-recipients. Unemployed people or renters are more exposed than employed people or homeowners. For SES factors at the municipal level, we found that living in a municipality with higher rates of industrial land use and foreign-born residents (mainly migrant workers and their family members) means a greater proximity to facilities that produce carcinogenic emissions.

In summary, our study confirmed that the carcinogenic facilities in Gyeonggi are inequitably distributed in regard to economic minority individuals (national basic livelihood security recipients, unemployed people, and tenants) and municipalities with higher percentages of industrial land use and foreign-born populations. Although similar findings can be found in many environmental justice studies conducted in other countries, to the best of our knowledge, this is the first Korean case study on the relationship between SES at both the individual and municipal levels and exposure to toxic chemicals. Therefore, the results of this study can be added to the general environmental justice literature as a Korean research case.

Continuous exposure to environmental risks can not only degrade the quality of life of individuals but also cause stress in the local community, hindering the sustainable development of the area [49]. Being exposed to harmful chemicals is a health risk for all but the inequitable distribution of risk can become a bigger burden to the socioeconomically disadvantaged populations, whose solvency regarding environmental costs is relatively insufficient. In addition, areas with a high percentage of socioeconomic minorities lack perception and protective action against environmental risks, becoming even more vulnerable to hazardous conditions [50]. In this vicious cycle, environmental risks can emerge as severe social problems because they interact with biological and socioeconomic vulnerabilities of the individuals and the environmental and socioeconomic conditions of the area [6,51].

To overcome the problem of environmental justice, it is important to focus on the reduction of environmental risks such as the release of toxic pollutants. Toxic release information systems such as PRTR have the ability to collect and share data, as well as the regulative function of enforcing industrial facilities to reduce the amount of toxic release [38]. Sharing the information not only promotes the community's active response but also, although sporadically, encourages industrial facilities to improve the environment through negative reactions of residents [52]. Therefore, the population should be informed about the PRTR through education and publicity. However, the information use varies with the social, political, and economic status of the community [53]. Therefore, it is important to increase the empowerment of the community and individuals so that they can respond appropriately to the environmental risks using the available information.

Because our study focused on Gyeonggi province, South Korea as a case study area, the findings of this study are limited to generalization. Therefore, further comparative studies are recommended by expanding the study areas to other regions in South Korea. Furthermore, this study considered only the number of facilities that produce carcinogenic emissions. However, the amount of releases and the risk levels may vary significantly depending on the facility and types of carcinogens. Thus, further studies are expected to elicit more specific results by considering the amount of the emissions and different risks levels by types of carcinogens.

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