Original Article
Yonsei Med J 2022 Aug;63(8):774-782
https://doi.org/10.3349/ymj.2022.63.8.774
Yonsei Medical Journal
YMJ
pISSN: 0513-5796 · eISSN: 1976-2437

Impact of Wildfire Smoke Exposure on Health in Korea

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Purpose: The characteristic topography and climate often affect the occurrence of large-scale wildfires in the Eastern Gangwon-do region of Korea. However, there are no studies on the health effects of these wildfires in Korea. This study aimed to analyze the differences in medical use between a wildfire-affected area and an adjacent non-affected area before and after a wildfire in 2019 in Gangwon-do, Korea.

Materials and Methods: We used medical usage data from the Korean National Health Insurance Corporation. Rates of medical use were determined for citizens of a wildfire-affected area in the Eastern Yeongdong region and a non-affected area in the Western Yeongseo region. Logistic regression analysis was performed considering an increase in medical use per individual as a dependent variable; age, sex, income, smoking, drinking, and exercise were included as confounding variables.

Results: The odds ratio for medical use in Yeongdong region increased significantly after 3 days, 3 months, and 1 year after a fire occurred, compared with Yeongseo region.

Conclusion: The results of this study confirmed that the use of medical care increased for residents of a wildfire-affected area, compared with those of an adjacent non-affected area. This is the first study on the relationship between wildfires and inpatient medical use in Korea.

Key Words: Wildfires, health impact, medical use, admission

INTRODUCTION

Approximately 400 wildfires occur annually in Korea.[1] Most wildfires occur in early April during the dry season. Large-scale wildfires occur frequently in the Eastern part of Gangwon-do (Yeongdong region) where there are many simple coniferous forests, mainly pine trees that are 20–30 years old, which are vulnerable to wildfires, as well as high temperature and dryness from the peon phenomenon.[2,3] On April 4, 2019, a massive wildfire occurred in Goseong and Sokcho, Gangwon-do. People in Goseong and Sokcho, who were exposed to wildfire smoke, were concerned about its potential health effects. At that time, there was a discernible difference between the wildfire-affected area in Eastern Gangwon-do and the Western part of Gangwon-do because of the atmospheric integrated environmental index and fine dust concentration due to the wildfire and a westerly wind.[4]

Wildfires do not result from the combustion of a single component, but from the burning of various vegetation, building, and other materials, which emit many air pollutants. The composition of wildfire smoke is complex and dynamic and hence difficult to characterize and model. However, it is generally known that carbon monoxide, nitrogen dioxide, ozone, particulate matter, polycyclic aromatic hydrocarbons, volatile organic compounds such as benzene, and various heavy met-

Received: March 14, 2022 **Revised:** May 11, 2022
Accepted: May 17, 2022
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•The authors have no potential conflicts of interest to disclose.

als are emitted from wildfire smoke. These contaminants reduce the oxygen-carrying capacity of the blood, resulting in tissue hypoxia, irritation of the nasal passages and respiratory tract, and a variety of pulmonary responses being induced, including reduced lung function, such as bronchoconstriction. Contaminants also elicit adverse hematological, neurological, and immunological effects. Wildfires are also known to increase the demand for health services and paradoxically reduce access to medical facilities. In addition, an increase in indoor pollution caused by wildfire combustion materials has been reported, along with health effects due to environmental pollution around the occurrence of wildfires.[5,6]

The health effects of gases and aerosols from wildfires are difficult to quantify. However, existing studies have shown that wildfire smoke contributes to eye, mucous membrane, and respiratory irritation, reduced lung function, bronchitis exacerbation, asthma, and heart failure, increasing hospital visits in smoke-exposed people. Dohrenwend, et al.[7] reported that the average number of visits to the emergency room significantly increased during the period when there was a fire by comparing the number of emergency room visits before and after a wildfire in California, America, a common area for wildfires. In Australia, where wildfires are also frequent due to the hot and dry climate and an abundance of eucalyptus trees, Hanigan, et al.[8] reported that the number of hospitalizations for respiratory diseases increased by 4.8% with an increase of 10 μg/m^3 of particulate matter (PM_{10}).

While previous studies on the health effects of wildfires have focused on acute effects that occur within days or weeks of exposure, Landguth, et al.[9] found that average $PM_{2.5}$ concentrations during wildfire season were positively correlated with flu outbreaks that occurred 1–10 months later. Henderson, et al.[10] estimated that air pollution from wildfires will induce systemic inflammation and cause long-term heart disease. However, further research is needed to determine whether exposure to wildfires has adverse long-term effects.

In Korea, there are few studies on the health effects of wildfires. Although previous studies have been conducted in other countries, it is necessary to study the health effects of wildfires in Korea because wildfires have combustion characteristics that differ depending on the topography, forest characteristics, and climate. After identifying the health effects of wildfires, we set out to confirm increased medical use caused upon the occurrence of wildfires and to examine the patterns of medical use to provide a basis for improving health monitoring and wildfire response systems after wildfires.

MATERIALS AND METHODS

Data description

The National Health Insurance Corporation (NHIS), operated by the Korean government, manages data on medical services provided to patients by all medical institutions in Korea.[11,12] The NHIS database contains information about medical institutions and patients, such as visit date and time, the total number of patients, claimed diagnosis, prescriptions, hospitalization and discharges, and medical services.[13] For comparison before and after wildfires among the customized data provided by the NHIS, from April 2017 to December 2019, the data on qualifications and insurance premiums, death, statement details, medical treatment details, diagnosis history, nursing institutions, and general health checkup questionnaire and the health checkup results were merged 2 years before the outbreak of a wildfire. Data from 2019 were used to assess health impacts after wildfires and were compared with data from 2018. For 2017 data, we confirmed the presence of underlying diseases among the study participants. Data analysis was performed from June 1, 2021 to July 31, 2021. Since the NHIS does not provide personally identifiable information to researchers, information that can identify patients was not used in the analysis. The research design was approved by the Research Deliberation Committee of Yonsei University Wonju Severance Christian Hospital (IRB No. CR320360).

Study subjects

The participants of this study were residents of Sokcho-si, Goseong-gun, Yanggu-gun, and Inje-gun in Gangwon-do, all of whom were enrolled in the health insurance system for 2018 and 2019.

Operational definition of disease

The operational definition of disease that we used is based on the 8th Korean Standard Classification of Causes of Diseases, Mental and Behavioral Disorders (F00–F99), Nervous System All Diseases (G00–G99), All Circulatory System Diseases (I00–I99), and Respiratory System Codes (J00–J99) in the categories of main and wounded diseases. Cases that included more than one disease were calculated as one.

Statistical analysis

We identified the number of medical users according to region (Yeongdong and Yeongseo), medical use (outpatient and hospitalization), period (before and after the wildfire), age (–19, 20–59, and 60–79), and period of medical use (≤3 days, ≤1 week, ≤1 month, ≤3 months, and ≤1 year). Analysis was performed by comparing the same periods of a year before and after the wildfire (e.g., April–July 2018 vs. April–July 2019). Since wildfires in spring and autumn are common in Korea due to the influence of westerly winds, temperature, and humidity,[2,14] we thought it better to compare the previous year of the wildfire we studied and the year after this wildfire, rather than a short-term comparison before and after this wildfire. Therefore, the medical utilization rate was calculated by dividing the number of inpatients from that period by the population during the middle of the year stratified by city or county/sex/age for the same peri-

od. Concerning the results of the calculated medical utilization rate, logistic regression was performed by region and sex to calculate odds ratio (OR) with reference to the number of hospitalized users under the age of 19 years for each period (April–July 2018 vs. April–July 2019) and sex. The reason for conducting an analysis of hospitalization among various types of medical services, such as outpatient, hospitalization, and emergency visit, is that emergency medical use can be affected by both the patients themselves and by people around them, such as family members and relatives. Although medical use is greatly affected by geological proximity of medical institutions, hospitalization holds an advantage in that the individual characteristics of users are relatively less affected, compared to outpatient treatment, because the need for hospitalization is highly dependent on the judgment of a medical professional, such as a doctor.[15] Logistic regression was performed considering an increase in medical use per individual as a dependent variable and with age, sex, income, smoking, drinking, and exercise as correction variables. The correction variables were included to adjust for demographic characteristics, socioeconomic status, and health behaviors that affect medical use. In 2019, the Ministry of Health and Welfare of Korea identified the Goseong, Sokcho, Yanggu, and Inje areas, included in our study, as vulnerable regions for emergency medical care. These regions were defined as areas with a vulnerability of 30% or more within an area of the population that could not reach a regional emergency medical center within 1 hour to a local emergency medical center within 30 minutes.[16] Additionally, according to an analysis of the health status of residents of Gangwon-do using data from regional community health surveys, there are minimal differences in smoking, drinking, and obesity rates between Yeongdong and Yeongseo regions.[17] Therefore, we assumed that there was no difference in infrastructure related to medical use in these regions and that age, sex, income, smoking, drinking, and exercise could be considered as factors that could make a difference in medical use between the two regions. To better understand ORs between age groups in each sex for Yeongdong and Yeongseo regions, we used "medical users under the age of 20 years and before the outbreak of wildfires" as a reference. Thereafter, the number of medical users was categorized only within the relevant period (3 days, 1 week, 1 month, etc.), and logistic regression analysis was performed using these categories. Additionally, when performing logistic regression analysis corrected for confounding variables, the frequency of medical use in the group under 20 years old was relatively low, compared to the other two groups, so it was analyzed as a continuous variable. All data processing and statistical analyses were performed using SAS 9.4 software (SAS Institute, Cary, NC, USA), and values of $p<0.05$ were considered significant.

RESULTS

Table 1 summarizes the number of medical users by region, period, sex, and age. The mid-year population was 105068.5 in the Yeongdong area (Goseong and Sokcho) and 53052.5 in the Yeongseo area (Inje and Yanggu) according to the Population Trend Survey by Statistics Korea in 2018. In 2019, there were 103108 people in Yeongdong and 51885 people in Yeongseo. The annual number of outpatients in 2018 was 71863 in Yeongdong and 37192 in Yeongseo. In 2019, it was 73756 and 38237, respectively. The annual number of hospitalizations in 2018 was 5644 in Yeongdong and 3178 in Yeongseo. In 2019, it was 6237 and 3378, respectively.

Table 2 shows the medical utilization rates, which were calculated by dividing the number of hospitalized medical users for each section by the mid-year population. Table 3 shows the resident registration populations by region, sex, and age from 2018 to 2019. In the Yeongdong area, the rate of inpatient medical use increased 3 months and 1 year after the fire for both male and female. The rate of inpatient medical use increased in all age groups (except for those aged 19 and under) 3 days, 1 week, and 1 month after the occurrence of the wildfire. In the case of the Yeongseo area, when compared to the Yeongdong area, the use of hospitalized medical care by period, age, and sex after the wildfire differed.

Limited to inpatient use, ORs were calculated to observe the effect of age on increased healthcare use, with reference to the number of medical users under the age of 19 years for each period and to sex to compare results before and after the wildfire. In the case of the wildfire area, the ORs for medical use increased for the same age groups in each period, whereas the control area decreased or showed only a slight increase (Table 4). In the Yeongdong area, the ORs for medical use increased in both men and women for all periods after the wildfire, except for the group under 19. On the other hand, in the Yeongseo region, the ORs for medical use increased 3 days after the wildfire and 1 year after the wildfire in men over 60 years. The ORs for medical use increased in women only 1 year after the wildfire.

According to multiple logistic regression analysis adjusted for age, sex, income (insurance premium), smoking, drinking, and exercise, the ORs [95% confidence interval (CI)] for an increase in medical use in the Yeongdong region, compared to Yeongseo region, at 3 days, 3 months, and 1 year after a wildfire occurred were as follows: 1.026 (1.001–1.051), 1.098 (1.084–1.111), and 1.029 (1.018–1.040), respectively (Table 5). In Tables 2, 3, and 4, age was set into three groups: 0–19 years old, 20–59 years old, and 60–79 years old. For the multiple logistic regression analysis with corrected confounding variables, the frequency of medical use in the group under 20 years was too low, compared to the other two groups, so it was analyzed as a continuous variable (Table 5).

Additional logistic regression analysis separately according to the presence or absence of an underlying disease indicated

https://doi.org/10.3349/ymj.2022.63.8.774

Table 1. Number of Medical Users by Region, Period, Sex, and Age

Age	Yeongdong								Yeongseo							
	Outpatient				Hospitalization				Outpatient				Hospitalization			
	Male		Female		Male		Female		Male		Female		Male		Female	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
3 days																
–19	978	826	932	779	7	4	7	5	614	551	531	544	8	9	2	4
20–59	1128	938	1396	1192	20	22	17	24	568	497	727	652	18	8	15	10
60–79	1374	1084	1801	1436	29	46	27	29	633	467	737	583	13	18	20	11
1 week																
–19	1464	1461	1414	1440	15	16	7	11	967	1018	913	924	16	16	8	10
20–59	1948	2200	2422	2726	45	56	44	64	965	1168	1297	1367	33	28	32	17
60–79	2384	2590	3245	3479	61	86	57	73	1117	1181	1277	1350	30	48	39	34
1 month																
–19	3192	3330	3006	3209	45	48	51	44	2055	2084	1888	1965	41	51	28	38
20–59	5948	6608	6932	7561	240	281	179	233	3159	3544	3738	3747	113	134	112	87
60–79	6546	6710	8444	8717	278	336	235	287	3071	3195	3503	3515	153	165	150	146
3 months																
–19	4543	4893	4352	4769	109	164	115	127	2831	2893	2645	2832	109	105	72	96
20–59	9997	11069	11624	12463	516	599	430	509	5472	6129	6156	6193	278	303	263	193
60–79	9145	9559	11230	11621	583	729	569	659	4588	4713	5001	5094	350	341	336	341
1 year																
–19	6389	6492	6186	6344	281	353	278	303	3723	3842	3587	3778	255	266	176	234
20–59	16532	17462	18683	19041	1225	1348	1063	1190	9147	9745	9314	9384	680	685	560	528
60–79	10917	11089	13156	13328	1396	1534	1401	1509	5551	5597	5870	5927	758	835	749	830

Table 2. Medical Utilization Rate* according to the Number of Hospitalized Medical Users (%)

Age	Yeongdong				Yeongseo			
	Male		Female		Male		Female	
	Before	After	Before	After	Before	After	Before	After
3 days								
–19	0.08	0.05	0.08	0.06	0.16	0.19	0.04	0.09
20–59	0.06	0.07	0.06	0.08	0.10	0.05	0.11	0.08
60–79	0.25	0.38	0.20	0.21	0.22	0.29	0.33	0.18
1 week								
–19	0.16	0.18	0.08	0.13	0.32	0.34	0.17	0.22
20–59	0.14	0.18	0.15	0.23	0.18	0.16	0.24	0.13
60–79	0.52	0.71	0.43	0.53	0.51	0.77	0.65	0.55
1 month								
–19	0.48	0.54	0.58	0.53	0.82	1.07	0.59	0.84
20–59	0.73	0.89	0.61	0.82	0.62	0.76	0.85	0.68
60–79	2.39	2.76	1.76	2.08	2.60	2.66	2.48	2.37
3 months								
–19	1.17	1.85	1.31	1.52	2.18	2.21	1.52	2.13
20–59	1.58	1.90	1.47	1.80	1.53	1.73	2.00	1.51
60–79	5.02	5.98	4.26	4.77	0.16	0.19	0.04	0.09
1 year								
–19	3.02	3.99	3.17	3.63	5.95	5.50	5.56	5.54
20–59	3.74	4.27	3.63	4.20	5.11	5.60	3.71	5.19
60–79	12.01	12.58	10.50	10.92	3.73	3.91	4.25	4.14

*The medical use rate [medical use rate=(B/A)*100, A=the number of people in the country; B=the number of medical users by section] was calculated using the resident registration populations by city/county/province/age for the period.

Table 3. The Mid-Year Population by Region, Sex, and Age (2018–2019)*

	2018				2019			
	Yeongdong		Yeongseo		Yeongdong		Yeongseo	
	Male	Female	Male	Female	Male	Female	Male	Female
–19	9314	8769	4993.5	4738	8857.5	8346	4746.5	4505
20–59	32735	29289.5	18224	13164.5	31577	28314.5	17535	12745.5
60–79	11620	13341.5	5887	6045.5	12196	13817	6196.5	6156.5
Total	53669	51400	29104.5	23948	52630.5	50477.5	28478	23407

*https://kosis.kr/statHtml/statHtml.do?orgId=101&tblId=DT_1B040M5&conn_path=I2.

that ORs for medical use in the Yeongdong region, compared to Yeongseo region, among individuals with an underlying disease increased significantly at 1 week, 1 month, 3 months, and 1 year after the wildfire as follows: 1.153 (1.013–1.313), 1.142 (1.067–1.223), 1.422 (1.362–1.485), and 1.112 (1.082–1.143), respectively (Table 6). The ORs for an increase in medical use in the group without underlying disease were also significantly increased at 3 days, 1 week, 3 months, and 1 year after the onset of the wildfire: 1.045 (1.020–1.071), 1.046 (1.028–1.065), 1.108 (1.096–1.120), and 1.079 (1.069, 1.090), respectively (Table 7). The ORs for each period were larger in the group with underlying diseases than in the group without underlying disease.

DISCUSSION

This study identified changes in medical use for areas affected by wildfires in Gangwon-do, Korea in April 2019. We confirmed that medical use was greater than that in a non-affected area adjacent to the wildfire-affected area.

In the case of Yeongdong, the wildfire-damaged area, OR values for medical use increased in the same age group in each period, while it decreased or slightly increased in the control area. In the case of men in both the Yeongdong and Yeongseo regions, the ORs for medical use increased as age increased in each period after the fire. In the case of women, the results were similar to those of men, except for the 20–50-year-old group in the Yeongdong region (Table 4).

From the logistic regression analysis with adjustment for confounding variables (Table 5), we noted that the greatest increase in OR values for medical use occurred in the Yeongdong region, compared to Yeongseo, after 3 months (OR=1.098, 95% CI=1.084–1.111). In addition, the OR value of the group with underlying diseases at 3 months after the fire was 1.422 (95% CI=1.362–1.485). This was larger than the OR value of 1.108 (95% CI=1.096–1.120) in the group without underlying diseases (Tables 6 and 7).

These results are consistent with those of previous studies on the health effects of wildfires. In a study by Morgan, et al.,[18] for every 10 μg/m^3 increase in PM_{10} concentration during a wildfire, the hospitalization rate for all respiratory diseases increased by 1.24% (Lag=0, 95% CI=0.22–2.27%), that for chronic obstructive pulmonary diseases increased by 3.80% (Lag=2, 95% CI=1.40–6.26%), and that for asthma increased by 5.02% (Lag=0, 95% CI=1.77–8.37%). In a 2002 study examining the health effects of wildfires in Quebec, Canada (in the Medicare population of the Northeastern United States and the mid-Atlantic), hospitalizations for when airborne smoke was present were 49.6% (95% CI=29.8–72.3%) and 64.9% (95% CI=44.3–88.5%) for respiratory and cardiovascular diagnoses, respectively, suggesting that smoke can affect the health of people thousands of kilometers away from a fire.[19] Liu, et al.,[6] Youssouf, et al.,[20] and Reid, et al.[21] reported through a systematic literature review that a strong association exists between asthma, chronic obstructive pulmonary disease (COPD), bronchitis, and exacerbation of pneumonia in a group exposed to wildfire smoke.

Several epidemiological studies have reported that exposure to wildfire smoke contributes to the exacerbation of asthma and chronic obstructive pulmonary disease. Martin, et al.[22] did not find any association with cardiovascular disease hospitalization, but confirmed an increase in hospitalization due to exacerbation of chronic lower respiratory tract diseases, such as asthma and COPD, and the possibility of cardiovascular side effects due to plant fire smoke exposure. Elliott, et al.[23] reported a 6% increase in the use of drugs to alleviate exacerbations of chronic respiratory disease during wildfire smoke exposure in British Columbia, representing an increase in COPD or asthma exacerbations.

Since 2000, the largest number of large-scale wildfires in Korea by region has occurred in Gangwon-do, followed by Gyeongsangbuk-do and Jeollabuk-do. The main causes of these results are coniferous forests, such as pine trees, which are vulnerable to high temperatures and dry weather conditions in spring in Gangwon-do, typhoon-class strong winds, and large-scale wildfires.[14] In contrast, the proportions of the older adult in Gangwon-do and Gyeongsangbuk-do are 21.2% in Gangwon-do and 22.2% in Gyeongsangbuk-do as of June 2021, which is a super-aged region.[24] In a 2017 study, Liu, et al.[25] observed that the risk of hospitalization for respiratory diseases increases with age during wildfires in older adults in the Western United States. Older adults and people with underlying diseases are sensitive groups that may be at higher risk; hence, a wildfire can cause many serious health side effects. Finally, the Gangwon-do region, as the subject of this study, is also one of the poorest in Korea, with an annual per capita income of 19174000 won

https://doi.org/10.3349/ymj.2022.63.8.774

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Table 4. ORs (95% CI) for the Number of Hospitalized Medical Users by Age Group for Period, Region, and Sex

Age	Yeongdong, OR (95% CI)				Yeongseo, OR (95% CI)			
	Male		Female		Male		Female	
	Before	After	Before	After	Before	After	Before	After
3 days								
–19	1	0.789 (0.222,2.807)	1	0.853 (0.270, 2.698)	1	1.246 (0.477, 3.251)	1	1.966 (0.359, 10.778)
20–59	2.834 (1.333, 7.085)*	3.749 (1.513, 9.287)*	1.585 (0.655, 3.836)	2.620 (1.124, 6.108)*	2.723 (1.024, 5.500)*	1.205 (0.449, 3.234)	5.364 (1.221, 23.554)*	3.987 (0.870, 18.276)
60–79	3.373 (1.395, 8.157)*	6.783 (2.884, 15.591)*	1.951 (0.846, 4.497)	2.628 (1.147, 6.024)*	1.538 (0.633, 3.736)	2.886 (1.244, 6.696)*	7.055 (1.642, 30.310)*	4.905 (1.082, 22.230)*
1 week								
–19	1	1.140 (0.554, 2.344)	1	1.544 (0.597, 3.996)	1	0.943 (0.469, 1.896)	1	1.130 (0.434, 2.941)
20–59	2.353 (1.287, 4.303)*	2.593 (1.438, 4.675)*	3.574 (1.605, 7.955)*	4.618 (2.111, 10.104)*	2.005 (1.096, 3.667)*	1.405 (0.756, 2.613)	2.753 (1.263, 6.002)*	1.388 (0.596, 3.229)
60–79	2.607 (1.453, 4.676)*	3.383 (1.916, 5.972)*	3.455 (1.572, 7.594)*	4.128 (1.896, 8.896)*	1.575 (0.853, 2.906)	2.383 (1.344, 4.223)*	3.408 (1.585, 7.327)*	2.810 (1.295. 6.098)
1 month								
–19	1	1.127 (0.729, 1.740)	1	0.774 (0.511, 1.173)	1	1.205 (0.795, 1.826)	1	1.284 (0.776, 2.123)
20–59	3.258 (2.307, 4.600)*	3.433 (2.440, 4.831)*	1.491 (1.087 2.047)*	1.780 (1.307, 2.423)*	1.718 (1.196, 2.466)*	1.816 (1.274, 2.587)*	2.009 (1.315, 3.070)*	1.557 (1.007, 2.407)*
60–79	3.429 (2.436, 4.825)*	4.043 (2.833, 5.670)*	1.607 (1.181, 2.188)*	1.902 (1.404, 2.575)*	2.392 (1.687, 3.393)*	2.480 (1.754, 3.507)*	2.872 (1.899, 4.343)*	2.786 (1.840, 4.216)*
3 months								
–19	1	1.437 (1.114, 1.853)*	1	0.980 (0.756, 1.271)	1	0.938 (0.713, 1.236)	1	1.252 (0.915, 1.714)
20–59	2.333 (1.798, 2.775)*	2.342 (1.889, 2.902)*	1.352 (1.096, 1.668)*	1.493 (1.214, 1.836)*	1.277 (1.017, 1.603)*	1.242 (0.992, 1.556)	1.532 (1.173, 2.003)*	1.118 (0.847, 1.475)
60–79	2.758 (2.224, 3.421)*	3.300 (2.669, 4.079)*	1.852 (1.509, 2.273)*	2.073 (1.692, 2.538)*	1.917 (1.536, 2.393)*	1.818 (1.456, 2.271)*	2.410 (1.855, 3.132)*	2.401 (1.849, 3.119)*
1 year								
–19	1	1.214 (1.030, 1.432)*	1	1.089 (0.917, 1.292)	1	1.005 (0.838, 1.204)	1	1.256 (1.025, 1.538)*
20–59	1.659 (1.449, 1.900)*	1.729 (1.511, 1.977)*	1.270 (1.105, 1.459)*	1.395 (1.216, 1.601)*	1.060 (0.912, 1.233)	1.002 (0.862, 1.165)	1.171 (0.983, 1.394)	1.095 (0.918, 1.306)
60–79	2.863 (2.503, 3.276)*	3.098 (2.710, 3.541)*	2.377 (2.074, 2.724)*	2.527 (2.207, 2.893)*	1.947 (1.676, 2.262)*	2.127 (1.834, 2.468)*	2.484 (2.094, 2.946)*	2.726 (2.302, 3.229)*

OR, odds ratio; CI, confidence interval.
*$p<0.05$.

per city and province.[26] A particulate matter-related health impact survey for large wildfires in northern California observed a linear increase in the risk of hospitalization for asthma (relative risk=1.07, 95% CI=1.05–1.10, per 5 ug/m^3 increase) in the summer of 2008, as well as a greater increase in respiratory emergency department visits for lower median incomes.[27] Another study reported that during the 2008 North Carolina fires at the Lake Pocosin National Wildlife Refuge increased emergency room visits for asthma and congestive heart failure were associated with poor socioeconomic conditions.[28] These socioeconomic characteristics of Gangwon-do can make the health effects of wildfires larger in this study, although the results of adjusting for income and age also showed significant results.

This study has several limitations. First, the national health

Table 5. Adjusted ORs and 95% CI for an Increase in Medical Use by Period, after Adjusting for Age, Sex, Income, Smoking, Drinking, and Exercise Variables

	3 days	*p* value	1 week	*p* value	1 month	*p* value	3 months	*p* value	1 year	*p* value
Region		0.045*		0.170		<0.001*		<0.001*		<0.001*
Yeongseo	Reference		Reference		Reference		Reference		Reference	
Yeongdong	1.026 (1.001, 1.051)		1.013 (0.995, 1.031)		0.939 (0.927, 0.952)		1.098 (1.084, 1.111)		1.029 (1.018, 1.040)	
Age*	0.994 (0.993, 0.995)	<0.001*	0.991 (0.990, 0.991)	<0.001*	0.974 (0.973, 0.974)	<0.001*	0.972 (0.972, 0.973)	<0.001*	0.991 (0.990, 0.991)	<0.001*
Sex		0.594		0.132		<0.001*		<0.001*		<0.001*
Male	Reference		Reference		Reference		Reference		Reference	
Female	0.993 (0.969, 1.018)		0.986 (0.968, 1.004)		0.947 (0.935, 0.961)		0.948 (0.937, 0.960)		0.898 (0.887, 0.908)	
Income	1.000 (1.000, 1.000)	0.016*	1.000 (1.000, 1.000)	0.029*	1.000 (1.000, 1.000)	<0.001*	1.000 (1.000, 1.000)	<0.001*	1.000 (1.000, 1.000)	<0.001*
Smoking		<0.001*		0.079		<0.001*		<0.001*		<0.001*
No	Reference		Reference		Reference		Reference		Reference	
Yes	0.885 (0.854, 0.917)		0.978 (0.953, 1.003)		1.106 (1.087, 1.126)		1.112 (1.094, 1.130)		1.251 (1.234, 1.268)	
Alcohol		0.004*		<0.001*		<0.001*		<0.001*		0.096
No	Reference		Reference		Reference		Reference		Reference	
Yes	0.958 (0.931, 0.986)		1.064 (1.042, 1.086)		0.968 (0.954, 0.983)		0.971 (0.958, 0.984)		0.990 (0.979, 1.002)	
Exercise		<0.001*		<0.001*		<0.001*		0.006*		<0.001*
No	Reference		Reference		Reference		Reference		Reference	
Yes	0.938 (0.916, 0.959)		0.947 (0.931, 0.962)		0.971 (0.959, 0.983)		1.016 (1.004, 1.027)		1.045 (1.035, 1.056)	

OR, odds ratio; CI, confidence interval.
*Age is adjusted as a continuous variable.

Table 6. Adjusted ORs and 95% CI for an Increase in Medical Use by Period, after Adjusting for Age, Sex, Income, Smoking, Drinking, and Exercise Variables (with Underlying Diseases)

	3 days	*p* value	1 week	*p* value	1 month	*p* value	3 months	*p* value	1 year	*p* value
Region		0.552		0.032*		<0.001*		<0.001*		<0.001*
Yeongseo	Reference		Reference		Reference		Reference		Reference	
Yeongdong	1.065 (0.865, 1.311)		1.153 (1.013, 1.313)		1.142 (1.067, 1.223)		1.422 (1.362, 1.485)		1.112 (1.082, 1.143)	
Age*	0.982 (0.973, 0.991)	<0.001*	1.004 (0.998, 1.010)	0.166	0.997 (0.994, 1.000)	0.039*	1.004 (1.002, 1.005)	<0.001*	1.003 (1.002, 1.004)	<0.001*
Sex		0.019*		<0.001*		0.660		0.614		0.087
Male	Reference		Reference		Reference		Reference		Reference	
Female	0.792 (0.652, 0.961)		1.305 (1.140, 1.494)		1.016 (0.946, 1.091)		0.989 (0.946, 1.034)		1.025 (0.996, 1.054)	
Income	1.000 (1.000, 1.000)	<0.001*	1.000 (1.000, 1.000)	<0.001*	1.000 (1.000, 1.000)	0.892	1.000 (1.000, 1.000)	<0.001*	1.000 (1.000, 1.000)	<0.001*
Smoking		<0.001*		<0.001*		<0.001*		<0.001*		<0.001*
No	Reference		Reference		Reference		Reference		Reference	
Yes	1.782 (1.320, 2.406)		2.563 (2.132, 3.080)		1.257 (1.147, 1.377)		1.160 (1.096, 1.228)		1.138 (1.098, 1.178)	
Alcohol		0.533		0.814		0.085		<0.001*		<0.001*
No	Reference		Reference		Reference		Reference		Reference	
Yes	1.088 (0.834, 1.419)		0.980 (0.830, 1.158)		1.075 (0.990, 1.167)		1.109 (1.054, 1.167)		1.090 (1.056, 1.125)	
Exercise		0.492		0.233		<0.001*		0.044*		0.370
No	Reference		Reference		Reference		Reference		Reference	
Yes	1.071 (0.881, 1.302)		0.923 (0.808, 1.053)		1.165 (1.090, 1.246)		1.043 (1.001, 1.086)		0.988 (0.963, 1.014)	

OR, odds ratio; CI, confidence interval.
*Age is adjusted as a continuous variable.

https://doi.org/10.3349/ymj.2022.63.8.774

Table 7. Adjusted ORs and 95% CI for an Increase in Nedical Use by Period, after Adjusting for Age, Sex, Income, Smoking, Drinking, and Exercise Variables (without Underlying Diseases)

	3 days	*p* value	1 week	*p* value	1 month	*p* value	3 months	*p* value	1 year	*p* value
Region		<0.001*		<0.001*		0.050*		<0.001*		<0.001*
Yeongseo	Reference		Reference		Reference		Reference		Reference	
Yeongdong	1.045 (1.020, 1.071)		1.046 (1.028, 1.065)		0.988 (0.976, 1.000)		1.108 (1.096, 1.120)		1.079 (1.069, 1.090)	
Age*	0.997 (0.996, 0.998)	<0.001*	0.995 (0.995, 0.996)	<0.001*	0.990 (0.990, 0.991)	<0.001*	0.993 (0.993, 0.993)	<0.001*	1.002 (1.002, 1.002)	<0.001*
Sex		0.768		0.376		0.209		<0.001*		<0.001*
Male	Reference		Reference		Reference		Reference		Reference	
Female	1.004 (0.979, 1.029)		0.992 (0.974, 1.010)		1.008 (0.995, 1.021)		1.049 (1.037, 1.061)		1.021 (1.011, 1.031)	
Income	1.000 (1.000, 1.000)	<0.001*	1.000 (1.000, 1.000)	0.192	1.000 (1.000, 1.000)	0.002*	1.000 (1.000, 1.000)	0.068	1.000 (1.000, 1.000)	<0.001*
Smoking		<0.001*		<0.001*		<0.001*		<0.001*		<0.001*
No	Reference		Reference		Reference		Reference		Reference	
Yes	0.867 (0.836, 0.898)		0.948 (0.925, 0.973)		1.045 (1.027, 1.063)		1.047 (1.032, 1.062)		1.101 (1.087, 1.115)	
Alcohol		0.044*		<0.001*		<0.001*		<0.001*		<0.001*
No	Reference		Reference		Reference		Reference		Reference	
Yes	0.971 (0.943, 0.999)		1.038 (1.016, 1.059)		0.938 (0.925, 0.951)		0.957 (0.945, 0.968)		1.024 (1.014, 1.035)	
Exercise		<0.001*		<0.001*		0.002*		<0.001*		<0.001*
No	Reference		Reference		Reference		Reference		Reference	
Yes	0.944 (0.923, 0.966)		0.948 (0.932, 0.964)		1.018 (1.006, 1.030)		1.023 (1.013, 1.034)		1.038 (1.029, 1.048)	

OR, odds ratio; CI, confidence interval.
*Age is adjusted as a continuous variable.

insurance data are documented as globally excellent data in terms of scale and diversity, but excludes foreigners and people whose place of residence is unclear. In addition, since not all people with health problems use hospitals, they cannot receive health insurance benefits, and as a result, if there are many cases where people with health disorders do not use medical institutions or are not treated, the total number of people with health problems may be underestimated. In addition, even when visiting a medical institution, misclassification of diseases or coding errors related to diagnosis names may occur. Second, in this study, the following diseases, including mental and behavioral disorders, diseases of the nervous system, circulatory system, and respiratory system were not analyzed separately. The analysis was conducted only to observe changes in overall medical use, so it was not possible to discern which disease group caused the increase in medical use. Future studies should examine the diseases that increased the most due to the occurrence of wildfires. Finally, the effects of a single wildfire in Goseong and Sokcho, the target regions of this study, may not represent the effects of other wildfires sufficiently. Sixteen wildfires occurred in Goseong, Sokcho, Yanggu, and Inje areas in Gangwon-do, Korea from April 4, 2018 to December 31, 2019. The health effects of extensive wildfire smoke exposure were investigated in the wildfire that occurred in Goseong and Sokcho on April 4, 2019, which was the fourth largest wildfire in Korea based on the damage area at the time of occurrence.[2] It was difficult to verify health data because the larger scale wildfires occurred in the late 1990s and early 2000s. In addition, wildfires are difficult to study because it is difficult to distinguish emissions, and there are many uncertainties in quantitative exposure assessments for individual exposure. Therefore, even in this study, it was not possible to directly measure health effects through accurate exposure assessments for participants.

Despite these limitations, the present study has several advantages. Korea's National Health Insurance provides the most reliable information on medical use in wildfire-affected areas with large-scale data, as it is mandatory for all medical providers and citizens to subscribe.

In conclusion, this study found that the use of medical care in a wildfire-affected area significantly increased the use of hospitalization, compared to a control area that possessed similar demographic characteristics. A systematic study on the health impact of the population group exposed to wildfires and a study on an approach system for sensitive groups are both necessary. This study hopes to serve as a basis for preparing a plan to provide appropriate medical care to residents when establishing a wildfire response system in the future.

AUTHOR CONTRIBUTIONS

Conceptualization: Kihyun Lee, Sang-Baek Koh, and Sung-Kyung Kim. Data curation: Se Hwa Hong and Dae Ryong Kang. Formal analysis: Se Hwa Hong. Investigation: Kihyun Lee and Kyoung Sook Jeong. Methodology: Kihyun Lee and Sang-Baek Koh. Project administration: Sei Jin Chang and Sung-Soo Oh. Resources: Sang-Baek Koh. Software: Dae Ryong Kang. Supervision: Yeon-Soon Ahn. Validation: Sei Jin Chang and Sung-Soo Oh. Writing—original draft: Kihyun Lee and Sung-Kyung Kim. Writing—review & editing: Kihyun Lee, Sang-Baek Koh, Sung-Kyung Kim, and Se Hwa Hong. Approval of final manuscript: all authors.

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https://doi.org/10.3349/ymj.2022.63.8.774