Systematic Review Article

Health Impacts of Environmental Stress: Case Studies of Fire, Oil Spills, and Air Pollution

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ABSTRACT

Environmental stressors impose substantial population-level health burdens and can contribute to increased disability-adjusted life year (DALY) burden and reduced quality of life. This paper examines short- and long-term health impacts of three major environmental stressors: wildfire smoke, marine oil spills, and chronic air pollution from coal-fired power plants. Using a narrative literature review, the study utilizes epidemiologic, toxicologic, and health systems evidence from various case studies, including the 2020 and 2025 California wildfire seasons, the 2007 Hebei Spirit oil spill in Taean, South Korea, and population level exposure to coal related fine particulate matter ($PM_{2.5}$). Amongst these three stressors, exposure to complex mixtures of particulate matter, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons, and combustion related pollutants was consistently associated with increased respiratory, cardiovascular, neurologic, and psychological morbidity. Evidence from longitudinal cohort studies and burden-of-disease analyses suggests that these impacts may extend beyond acute exposure periods and be associated with prolonged healthcare utilization, chronic disease risk, and mental health distress. For the Hebei Spirit oil spill case study, a burden-of-disease analysis estimated approximately 14,724 DALYs attributable to the spill in 2008 (5). Analysis of healthcare utilization following the Hebei Spirit oil spill illustrates significant specialty-specific disruptions and patterns of delayed recovery, reflecting both toxic exposure pathways and broader social and healthcare system stress. Environmental disasters and chronic pollution may function as important contributors to lasting population-level health burden. Integrating environmental exposure assessment into public health assessments and strengthening preventive policies are essential to mitigating the long-term consequences of increasingly frequent environmental stress incidents.

Keywords: $PM_{2.5}$ Air Pollution; Oil Spill Health Impacts; Wildfire Smoke Exposure; Coal Fired Power Plants; Environmental Stressors

INTRODUCTION

Despite advances in the prevention and treatment of many diseases that reduce overall disease burden and improve quality of life, environmental stressors play a significant and often underestimated determinant of population health. Climate change, industrial activity, and excessive energy production in order to meet the demand, have increased the frequency, intensity, and scale of environmental exposures that affect human health through various complex pathways (1). Among the

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many environmental stressors affecting human health, wildfire smoke, marine oil pollution, and chronic air pollution from coal-fired power plants were selected because they represent contrasting exposure patterns and temporal scales: acute episodic smoke exposure, disaster-related regional contamination, and chronic long-term atmospheric pollution (2). Examining these three categories allows comparison across distinct mechanisms of exposure and healthcare system impact while maintaining a shared focus on combustion- or petrochemical-related pollutants.

Yearly trends reveal increased global occurrence and its impact of wildfires, which produce acute episodes of hazardous air pollution characterized by high concentrations of $PM_{2.5}$ and combustion derived chemicals (1). Large scale oil spills result in lasting environmental contamination and long-term health consequences for affected coastal populations. Coal fired power plants and their continuous emission of particulate matter and gaseous pollutants contribute to chronic disease burden at regional and national level. This review examines the chemical exposure, its short-term and long-term health effects, and healthcare utilization patterns associated with these three environmental stressors.

METHODS AND MATERIALS

This study utilized a mixed methods design combining a narrative literature review with a secondary analysis of national administrative healthcare utilization data. The literature review was conducted to create epidemiologic and toxicologic evidence on the health impacts of environmental stressors, including wildfire smoke, large scale oil spills, and chronic air pollution from coal fired power plants. The quantitative component of the study aimed to contextualize these findings by examining post disaster healthcare utilization patterns following the Hebei Spirit oil spill in Taean, South Korea in 2007.

Literature Review Strategy

A narrative literature review was conducted to identify peer-reviewed studies examining both short- and long-term human health effects of environmental pollution. Electronic databases including PubMed, Web of Science, and Scopus were searched for articles published between January 1990 and December 2025, a period selected to capture temporal changes in environmental exposure patterns and associated health outcomes.

Search terms were developed using combinations of keywords related to exposure type and health outcomes, including “wildfire smoke,” “oil spill,” “air pollution,” “coal-fired power plant,” “particulate matter,” “environmental exposure,” “health outcomes,” “epidemiology,” and “toxicology.” Boolean operators (AND/OR) were applied to refine searches. Reference lists of relevant review articles were also manually screened to identify additional studies.

Titles and abstracts were initially screened to exclude studies unrelated to human health outcomes or environmental exposure. Full-text review was then performed to assess eligibility. Studies were included if they (1) reported human health outcomes associated with environmental exposure, (2) provided quantitative, clinical, or epidemiologically relevant findings, and (3) employed clearly defined exposure assessment methods. Animal studies, purely mechanistic laboratory studies, and articles lacking primary data were excluded.

Although this review did not follow a formal systematic review protocol, study quality was assessed qualitatively based on study design, sample size, exposure characterization, outcome measurement, and appropriateness of statistical analysis. Priority was given to large cohort studies, longitudinal analyses, and investigations conducted in geographically isolated or well-defined exposure settings with limited confounding from alternative environmental stressors.

Healthcare Utilization Data Source

Quantitative analysis was conducted using administrative healthcare utilization data obtained from the Health Insurance Review and Assessment Service (HIRA) of South Korea. Annual outpatient visit counts stratified by medical specialty were extracted for residents of Chungcheongnam-do from the Local Public Health Medical Reports for the years 2007 through 2011. This dataset captures healthcare utilization for the majority of the population covered under the national health insurance system and provides population-level, specialty-specific information suitable for longitudinal trend analysis.

Healthcare utilization trends were assessed using descriptive longitudinal comparisons of annual outpatient visit counts across the study period. The year 2007, corresponding to the Hebei Spirit oil spill, was treated as the baseline period, and subsequent years were examined to identify relative changes in utilization patterns during the post-spill recovery phase. Changes were evaluated by comparing year-to-year differences and overall directional trends across medical specialties.

Given the aggregate and administrative nature of the data, formal individual-level inferential statistical testing

was not conducted. Instead, observed temporal patterns were interpreted in conjunction with epidemiologic evidence from the literature review to contextualize potential health impacts following the environmental disaster. This approach was selected to align with the study's exploratory and contextual objectives.

Potential confounding factors, including population displacement, changes in healthcare access, and policy or reporting shifts, were considered during interpretation of results. However, adjustment for these factors was limited by the absence of individual-level demographic data and detailed migration or policy indicators within the publicly available dataset.

RESULTS AND DISCUSSION

Wildfire and Urban Fire Smoke

Evidence from epidemiologic and toxicologic studies indicates that wildfire smoke exposure is associated with a range of acute and long-term health outcomes. California has become one of the most prominent examples, notably during the 2020 and 2025 California wildfire seasons, which were associated with substantial destruction and periods of severe smoke exposure (2). The major chemical constituents of wildfire smoke and their associated biological effects are summarized in Table 1.

Short-Term Health Effects of Wildfire Smoke Exposure

Short-term exposure to wildfire smoke has been consistently associated with acute increases in respiratory morbidity. Epidemiologic studies have demonstrated immediate rises in emergency department visits and hospital admissions for asthma, bronchitis, pneumonia, and other lower respiratory conditions during wildfire events (3). Evidence from large urban fire events has similarly reported acute respiratory effects following short-term smoke exposure (4). Meta analytic evidence indicates that each incremental increase in wildfire specific $PM_{2.5}$ is associated with statistically significant increases in same-day respiratory hospitalizations and emergency department utilization (3).

Acute effects are not limited to the respiratory system. Exposure to wildfire smoke has also been linked to eye irritation, conjunctivitis, headaches, and steady neurologic symptoms, reflecting the irritant and neurotoxic properties of airborne pollutants (3).

While evidence for short-term cardiovascular effects is more varying, studies consistently report heightened risks of cardiovascular hospitalizations and mortality during periods of intense smoke exposure, particularly among older adults and individuals with preexisting health condition (3).

Table 1. *Major Chemical Constituents of Wildfire Smoke and Associated Health Effects. Principal chemical constituents of wildfire smoke and their documented biological effects on human health. Information is summarized from epidemiologic and toxicologic reviews of wildfire smoke exposure.*

Chemical / Pollutant	Primary Biological Effects	Health Outcomes Commonly Observed
$PM_{2.5}$	Penetrates deep into alveoli; induces oxidative stress and systemic inflammation	Asthma exacerbation, decreased lung function, increased respiratory hospitalizations, all-cause mortality
Carbon monoxide (CO)	Reduces oxygen delivery by binding hemoglobin; causes tissue hypoxia	Headache, dizziness, cardiovascular strain, acute poisoning at high exposure
Nitrogen oxides (NO_x)	Airway irritation; contributes to secondary ozone formation	Bronchial inflammation, worsened asthma symptoms
VOCs	Neurotoxic and irritant properties; some compounds are carcinogenic	Mucosal irritation, neurologic symptoms, long-term cancer risk
Polycyclic aromatic hydrocarbons (PAHs)	DNA damage and endocrine disruption; many are carcinogenic	Increased cancer risk, immune dysregulation
Aldehydes (e.g., formaldehyde, acrolein)	Potent respiratory irritants; oxidative injury	Upper and lower respiratory tract irritation, conjunctivitis
Heavy metals (e.g., lead, mercury)	Neurotoxicity and systemic toxicity	Cognitive impairment, cardiovascular effects

Long-Term and Delayed Health Effects of Wildfire Smoke Exposure

Beyond acute morbidity, growing evidence suggests that wildfire smoke exposure may contribute to longer-term health consequences. Prolonged exposure to wildfire derived $PM_{2.5}$ has been associated with sustained reductions in lung function, increased incidence of chronic respiratory disease, and persistent inflammatory responses (3).

Emerging literature also links wildfire smoke exposure to adverse pregnancy outcomes, including preterm birth and low birth weight, likely mediated by systemic inflammation and maternal stress pathways (3, 10). In addition, associations with mental health outcomes such as anxiety, depression, and post-traumatic stress symptoms have been reported, reflecting both the direct neuroinflammatory effects of smoke exposure and the psychosocial stressors associated with wildfire events and displacement (1, 3)

Marine Oil Spill Exposure

The Hebei Spirit Oil Spill in Taean, South Korea in 2007 was followed by one of the most comprehensive examinations of long-term health outcomes. The Hebei Spirit oil spill provides a uniquely well-documented case study due to the geographic containment of the contamination and the availability of comprehensive healthcare utilization data (5).

Based on these findings, Health Effect Research on Hebei Spirit Oil Spill (HEROS) was established as a prospective cohort study that followed nearly 10,000 adults and over 2,000 children from affected communities beginning in 2009.

Evidence from epidemiologic studies of the Hebei Spirit oil spill indicates that populations exposed to crude oil contamination experienced multiple health effects associated with VOC and PAH exposure. The Hebei Spirit oil spill, which released approximately 12,547 kiloliters of crude oil into coastal waters of South Korea, Taean in December 2007, provides one of the most extensively studied examples of population level health impacts following marine oil pollution (6). Crude oil contains VOCs such as benzene, toluene, ethylbenzene, and xylene, as well as polycyclic aromatic hydrocarbons, several of which are known to be carcinogenic or neurotoxic. Exposure to these substances has been associated with respiratory irritation, allergic conditions, hematologic abnormalities and psychological distress. Table 2 summarizes the major toxic substances released during the Hebei Spirit oil spill and the clinical specialties most likely to be affected by these exposures.

Quantitative assessment of health burden following

Table 2. *Major Toxic Substances Released During the Hebei Spirit Oil Spill and Associated Health Effects by Medical Specialty. This table summarizes major chemical substances released during the Hebei Spirit oil spill and the primary health effects associated with human exposure. Listed exposures include VOCs, polycyclic aromatic hydrocarbons, and crude oil–related aerosols encountered through inhalation, dermal contact, and environmental contamination. The associated medical specialties reflect clinical services most likely to experience increased healthcare utilization following oil spill exposure, based on documented physical and psychological health outcomes among affected residents. (6, 5).*

Chemical / Substance	Primary Health Effects	Relevant Medical Specialties
Benzene (VOCs)	Hematologic toxicity including bone marrow suppression; increased risk of leukemia with chronic exposure; neurological symptoms such as dizziness and headaches	Internal Medicine (Hematology), Neurology
Toluene (VOCs)	Central nervous system depression, cognitive impairment, headaches, dizziness; respiratory irritation	Neurology, Internal Medicine
Ethylbenzene (VOCs)	Respiratory tract irritation; inner ear toxicity; potential neurobehavioral effects	Internal Medicine, Otolaryngology (ENT)
Xylenes (VOCs)	Eye and skin irritation; respiratory symptoms; neurocognitive effects with prolonged exposure	Ophthalmology, Internal Medicine, Neurology
Polycyclic Aromatic Hydrocarbons (PAHs)	Carcinogenicity; oxidative stress; DNA damage; endocrine disruption; dermatologic irritation	Internal Medicine, Dermatology, Oncology

Continued Table 2. *Major Toxic Substances Released During the Hebei Spirit Oil Spill and Associated Health Effects by Medical Specialty. This table summarizes major chemical substances released during the Hebei Spirit oil spill and the primary health effects associated with human exposure. Listed exposures include VOCs, polycyclic aromatic hydrocarbons, and crude oil–related aerosols encountered through inhalation, dermal contact, and environmental contamination. The associated medical specialties reflect clinical services most likely to experience increased healthcare utilization following oil spill exposure, based on documented physical and psychological health outcomes among affected residents. (6, 5).*

Chemical / Substance	Primary Health Effects	Relevant Medical Specialties
Particulate Oil Aerosols	Airway inflammation; asthma exacerbation; reduced pulmonary function	Internal Medicine (Pulmonology), Family Medicine
Sulfur containing compounds (from crude oil volatilization)	Upper airway irritation; bronchoconstriction; mucosal inflammation	Otolaryngology (ENT), Internal Medicine
Heavy Metals (trace components in crude oil)	Oxidative stress; renal and neurologic toxicity; hematologic effects	Internal Medicine, Nephrology, Neurology
Oil Dispersants & Degradation Products	Skin irritation; chemical dermatitis; potential endocrine effects	Dermatology, Family Medicine
Psychosocial Stressors (disaster exposure, cleanup work)	Post-traumatic stress disorder, depression, anxiety, sleep disturbance	Psychiatry, Family Medicine
Oxidative Stress Biomarkers (e.g., malondialdehyde, 8-OHdG)	Cellular damage; inflammation; long-term cardiopulmonary risk	Internal Medicine, Cardiology

the Hebei Spirit spill estimated a substantial DALY burden among residents of contaminated coastal areas. Using a DALY approach, Kim *et al*. estimated that approximately 14,724 DALYs in 2008 were attributable to the oil spill, with major contributions from mental health disorders (e.g., post-traumatic stress disorder and depression) as well as asthma and allergic diseases (6). Reported burden varied by age and sex, and higher burden was observed among residents living closer to the contaminated coastline, consistent with exposure gradients (6).

Longitudinal evidence from the HEROS cohort add further supports to the persistence of health effects beyond the immediate results of the disaster. Follow up assessments documented reduced pulmonary function and higher prevalence of allergic rhinitis among children living closer to the spill site. Among adults, residents in highly exposed areas and those who participated extensively in cleanup activities exhibited elevated urinary biomarkers of oxidative stress, changes in hematologic parameters, and sustained psychological symptoms, including depression and post-traumatic stress (5).

The trends observed in Figure 1 are consistent with the known health consequences of large-scale oil spill exposure documented in prior epidemiological studies. Declines in overall patient volume immediately following the spill likely reflect acute disruptions to healthcare access and population displacement. However, specialty specific patterns suggest more targeted health effects over time.

Reductions and subsequent rebounds in internal medicine, otolaryngology, ophthalmology, and anesthesiology and pain medicine are consistent with increased respiratory, mucosal, and pain associated conditions linked to exposure to crude oil exposure containing VOCs and polycyclic aromatic hydrocarbons. Furthermore, sustained utilization in neurosurgery and general surgery may reflect delayed presentation of neurological symptoms, injury related conditions, or chronic disease triggered by stress.

In contrast, smaller fluctuations in urology and orthopedic surgery suggest these specialties were less directly affected by oil related toxic exposure, serving as positive control points for baseline healthcare demand. The gradual decline observed in traditional

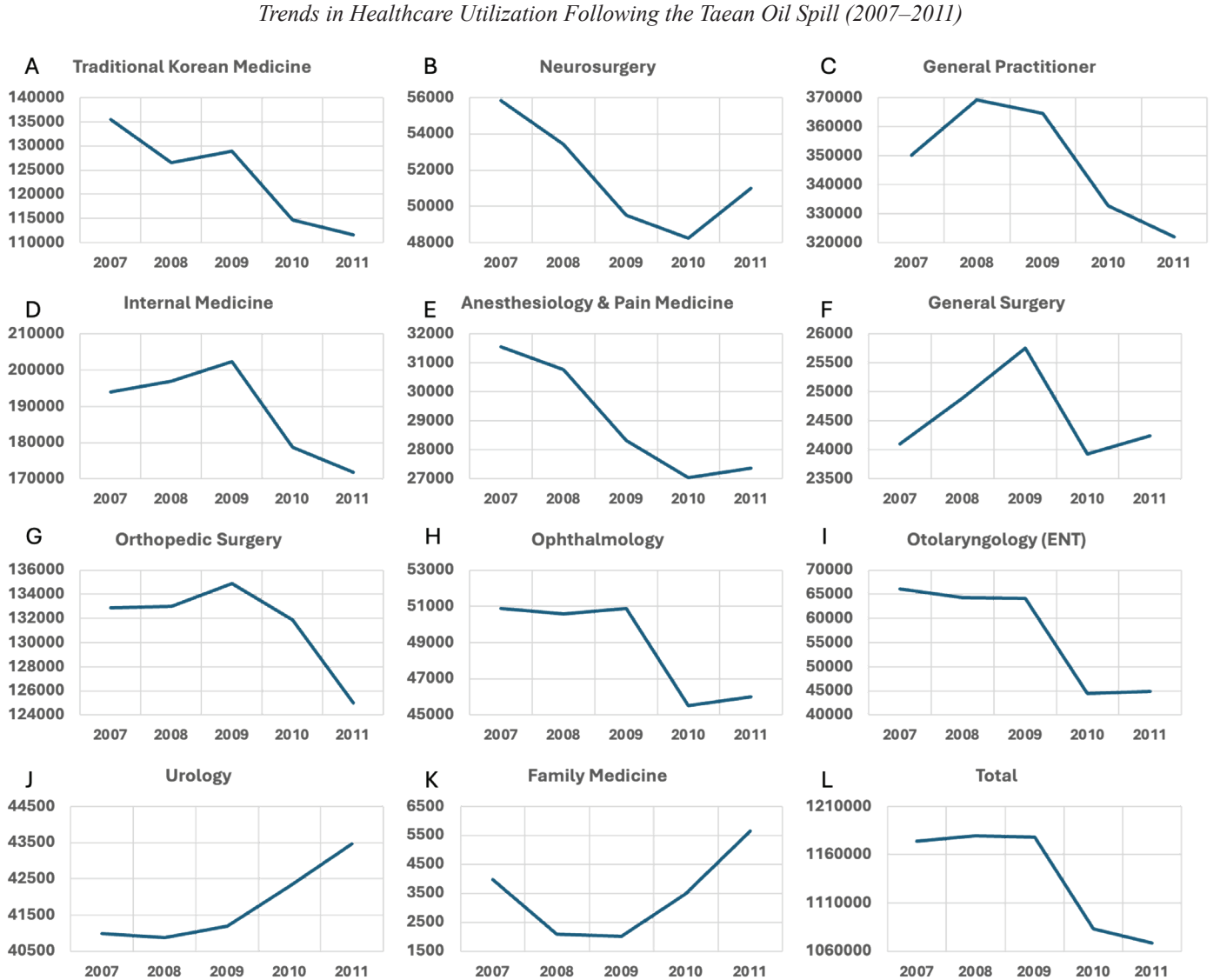

Figure 1. *Trends in outpatient healthcare utilization by medical specialty following the 2007 Hebei Spirit oil spill in Taean, South Korea (2007–2011). Annual outpatient visit counts are shown for each specialty, with separate panels labeled A–L: A, Traditional Korean Medicine; B, Neurosurgery; C, General Practitioner; D, Internal Medicine; E, Anesthesiology & Pain Medicine; F, General Surgery; G, Orthopedic Surgery; H, Ophthalmology; I, Otolaryngology (ENT); J, Urology; K, Family Medicine; and L, Total outpatient visits across all included specialties. The x-axis indicates calendar year (2007–2011), and the y-axis indicates annual outpatient visit counts. Data were obtained from the Health Insurance Review and Assessment Service (HIRA), Local Public Health Medical Report (Chungcheongnam-do), 2022 (7).*

Korean medicine utilization may reflect broader shifts in healthcare seeking behavior during post disaster recovery rather than direct toxicological effects.

In summary, the observed findings support the interpretation that the Hebei Spirit oil spill generated both acute and prolonged health impacts, with disproportionate effects on specialties associated with respiratory, allergic, neurological, and psychological conditions. This also align with population level burden of disease estimates and longitudinal cohort evidence demonstrating a continued presence of physical and mental health consequences among exposed residents.

The percentage change analysis reveals pronounced heterogeneity across medical specialties in response to

the Hebei Spirit oil spill (Figure 2). Substantial declines in outpatient visits were observed in the years immediately following the spill, particularly around 2009–2010, coinciding with peak environmental contamination and prolonged clean-up activities. Specialties associated with respiratory, sensory, and allergic conditions, including internal medicine, otolaryngology, and ophthalmology, demonstrated marked decreases during this period, followed by partial recovery.

In contrast, traditional Korean medicine and anesthesiology and pain medicine exhibited gradual increases in utilization in the later post spill years.

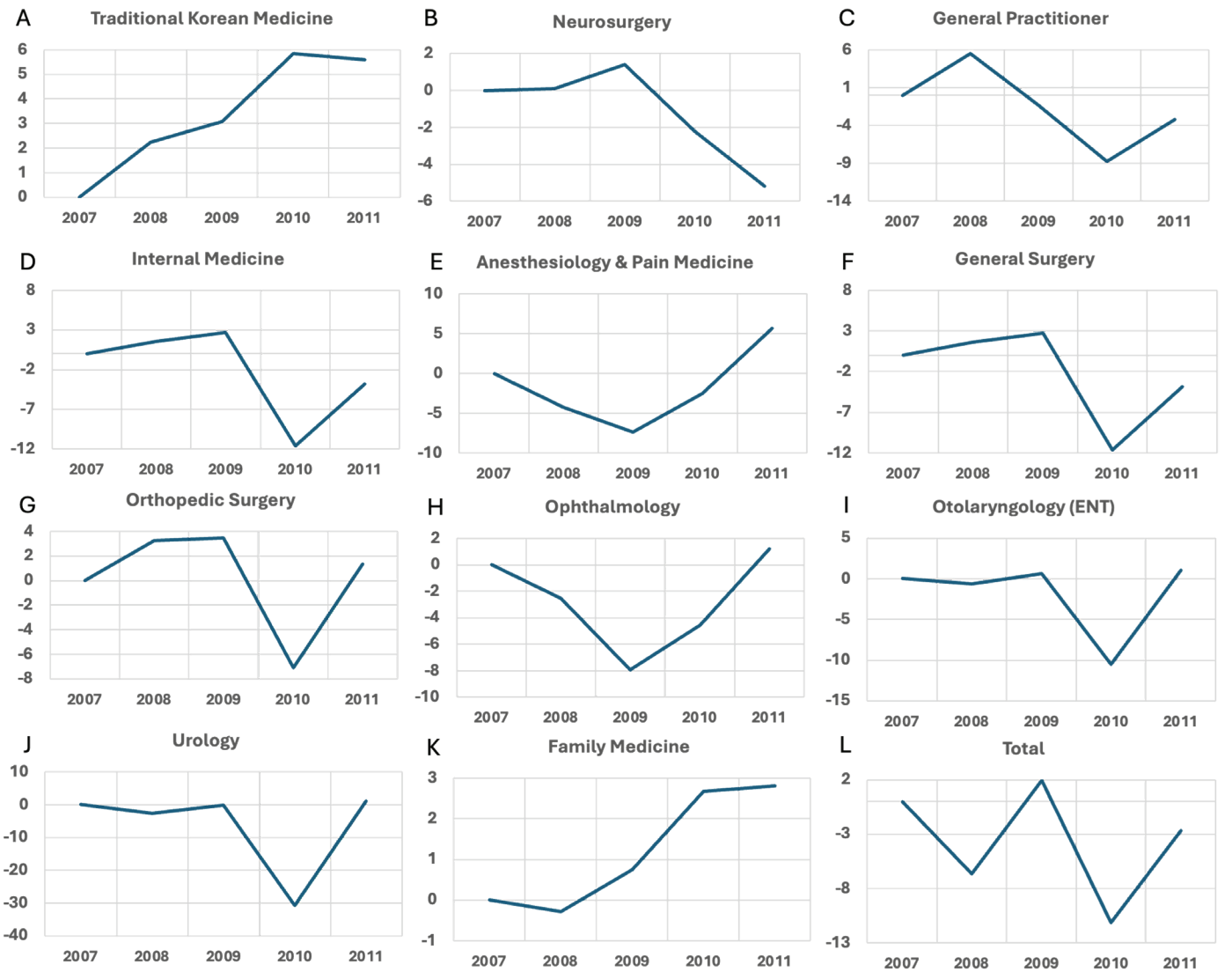

Figure 2. *Year-to-year percent change in outpatient visits by medical specialty following the 2007 Hebei Spirit oil spill in Taean, South Korea (2007–2011). Percent changes are calculated relative to the baseline year 2007 (0%). Panels are labeled as follows: A, Traditional Korean Medicine; B, Neurosurgery; C, General Practitioner; D, Internal Medicine; E, Anesthesiology & Pain Medicine; F, General Surgery; G, Orthopedic Surgery; H, Ophthalmology; I, Otolaryngology (ENT); J, Urology; K, Family Medicine; and L, Total outpatient visits across all included specialties. Negative values indicate reductions relative to baseline, whereas positive values indicate increases. The horizontal reference line denotes no change from baseline levels. Data were obtained from the Health Insurance Review and Assessment Service (HIRA), Local Public Health Medical Report (Chungcheongnam-do), 2022 (7).*

These trends may reflect the emergence of chronic pain syndromes, musculoskeletal complaints, and persistent stress related symptoms, which have been documented among residents and clean up participants in long-term cohort studies (5). Surgical specialties, including general surgery and orthopedic surgery, showed steady declines with incomplete recovery, suggesting that elective and non-urgent procedures may have been deferred during periods of heightened environmental stress and economic disruption.

Overall, the total outpatient visits trajectory mirrors these specialty specific patterns, with a notable decline in the immediate aftermath of the spill and only partial normalization by 2011. These findings align with prior evidence that large scale oil spills exert both acute and prolonged impacts on healthcare utilization, reflecting a combination of toxic exposure, psychological stress, disruption of healthcare access, and shifts in medical need over time (6).

The aggregated trends shown in Figure 3 highlight heterogeneous healthcare utilization responses across medical specialties following the Hebei Spirit oil spill. Specialties associated with respiratory exposure and mucosal irritation, such as internal medicine, otolaryngology, and ophthalmology, exhibited marked declines during the period of greatest disruption, followed by partial rebound. Pain related and integrative care specialties, including anesthesiology and traditional Korean medicine, demonstrated delayed increases, suggesting prolonged symptom burden and chronic health concerns. In contrast, surgical specialties showed sharper short-term declines, consistent with postponement of non-emergency care during periods of environmental and social disruption. Healthcare utilization data used to generate all figures were obtained from the Health Insurance Review and Assessment Service (HIRA) Local Public Health Medical Reports for Chungcheongnam-do. The dataset includes annual outpatient visit counts by medical specialty from 2007 to 2011 and covers the majority of residents in the affected Taean region.

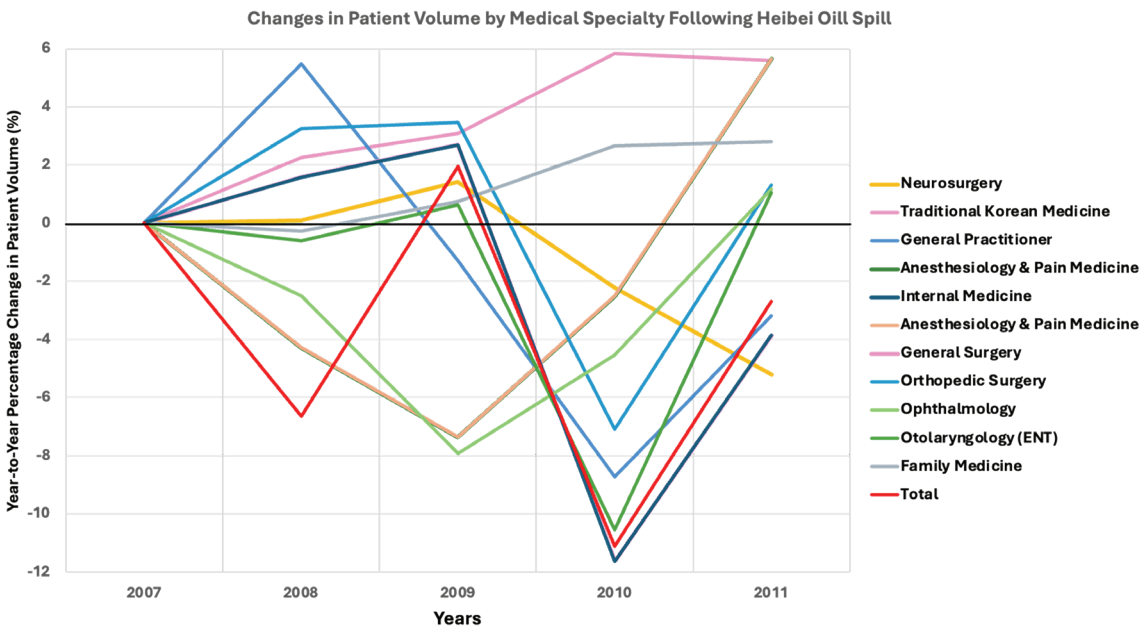

Figure 3. *Relative changes in outpatient visits by medical specialty following the Hebei Spirit oil spill in Taean, South Korea (2007–2011). This figure overlays year-to-year percentage changes in outpatient visits across multiple medical specialties, using 2007, the year of the oil spill, as the baseline (0%). Each colored line represents a distinct medical specialty. Negative values indicate reductions in outpatient visits relative to baseline, while positive values indicate increases. The pronounced decline across several specialties in 2010 reflects a period of widespread healthcare utilization disruption following the spill, followed by partial recovery in 2011. Data obtained from the Health Insurance Review and Assessment Service (HIRA), Local Public Health Medical Report (Chungcheongnam-do), 2022 (7).*

Oil Spill: Interpretation and Integration with Prior Evidence

The observed healthcare utilization patterns are consistent with known toxicologic and epidemiologic pathways associated with crude oil exposure, as well as broader social and healthcare system disruption following environmental disasters (5, 6). Sustained utilization in anesthesiology, pain medicine, and traditional Korean medicine may reflect prolonged symptom burden and psychological stress, as documented in longitudinal cohort studies of exposed residents and cleanup participants (5). In contrast, relative stability in urology and orthopedic surgery utilization suggests these specialties may have been less directly affected by oil-related toxic exposure, serving as internal comparators. Therefore, the convergence of cohort, burden-of-disease, and healthcare utilization evidence suggests that large-scale marine oil spills may be associated with prolonged health system impacts beyond the acute disaster period (5, 6, 7).

Coal Fired Power Plants Emissions

Multiple epidemiologic and health impact assessment studies indicate that emissions from coal-fired power plants contribute substantially to population-level disease burden. Emissions from coal combustion include both primary pollutants directly released into the atmosphere and secondary pollutants formed through atmospheric chemical reactions. Among these, $PM_{2.5}$ with an aerodynamic diameter ≤ 2.5 μm ($PM_{2.5}$) has been identified as the dominant mediator of adverse health outcomes associated with coal derived air pollution.

Major Pollutants Emitted from Coal Fired Power Plants

Coal combustion releases a complex mixture of pollutants, including sulfur dioxide (SO_2), nitrogen oxides (NO_x), primary and secondary $PM_{2.5}$, VOCs, and trace metals. SO_2 and NO_x contribute to the formation of sulfate and nitrate aerosols, which substantially increase ambient $PM_{2.5}$ concentrations downwind of power plants. These particles can remain airborne for extended periods and affect populations far beyond the immediate vicinity of emission sources (8, 9, 10). Table 3 summarizes the primary pollutants emitted from coal-fired power plants and their associated health effects.

Health Effects Associated with $PM_{2.5}$ Exposure

As discussed above, these evidence reveals that chronic exposure to $PM_{2.5}$ from coal fired power plants is associated with increased morbidity and mortality from cardiovascular and respiratory diseases. Accountability analyses in the United States have shown that reductions in coal related emissions between 2005 and 2012 were associated with statistically significant declines in hospitalizations for ischemic heart disease, heart failure, stroke, chronic obstructive pulmonary disease, and respiratory infections among Medicare beneficiaries (8). Most notably, health benefits were more altered when exposure reductions were attributed specifically to coal derived pollution rather than to total $PM_{2.5}$ alone, highlighting the irregular toxicity of coal combustion emissions.

Health impact assessments further indicate that even a small increase in exposure of long-term $PM_{2.5}$

Table 3. *Major Pollutants from Coal Fired Power Plants and Associated Health Effects. The table summarizes primary combustion pollutants, their dominant exposure pathways, and associated health outcomes based on epidemiologic and health impact assessment studies. Evidence is drawn from accountability analyses of coal emission reductions, population level $PM_{2.5}$ health impact modeling, and pediatric environmental health literature.*

Pollutant	Primary Source in Coal Combustion	Major Health Effects
$PM_{2.5}$	Primary emissions and secondary formation from SO_2 and NO_x	Cardiovascular disease, stroke, heart failure, COPD, respiratory infections, premature mortality
Sulfur dioxide (SO_2)	Coal sulfur content	Respiratory irritation; precursor to sulfate $PM_{2.5}$
Nitrogen oxides (NO_x)	High temperature combustion	Formation of nitrate $PM_{2.5}$; asthma exacerbation
Trace metals (e.g., arsenic, chromium)	Coal impurities	Carcinogenicity; cardiovascular toxicity
VOCs	Incomplete combustion	Oxidative stress; systemic inflammation

concentrations caused by coal fired power plants can lead to measurable increases in premature mortality. Modeling studies from Taiwan estimated that $PM_{2.5}$ emissions from a single planned coal fired power plant would contribute to excess deaths from ischemic heart disease, stroke, lung cancer, and chronic obstructive pulmonary disease over subsequent decades (9).

Children represent a particularly vulnerable population. Exposure to chronic $PM_{2.5}$ level and other pollutants derived from combustion has been linked to impaired lung development, increased asthma incidence, neurodevelopmental effects, adverse birth outcomes, and elevated lifetime risk of chronic disease. These effects are mediated through oxidative stress, systemic inflammation, endocrine disruption, and epigenetic mechanisms, which may exert long-lasting and potentially irreversible impacts throughout one's life (10).

Coal-Fired Power Plants: Interpretation and Policy Relevance

These findings suggest that coal-derived air pollution represents a preventable contributor to chronic disease burden. Evidence indicating greater toxicity of coal combustion–related $PM_{2.5}$ relative to total ambient particulate matter underscores the importance of source-specific exposure assessment in environmental health research (8, 9).

Observed improvements in population health following reductions in coal emissions highlight the potential for regulatory and policy interventions to mitigate long-term health impacts associated with chronic air pollution exposure (8). Strengthening emission controls and accelerating transitions away from coal-based energy production may therefore yield substantial public health benefits.

CONCLUSION

Across wildfire smoke exposure, marine oil pollution, and coal-related air pollution, consistent associations were observed between environmental stressors and adverse health outcomes affecting respiratory, cardiovascular, neurologic, and psychological systems (3, 4, 5). Evidence synthesized from epidemiologic studies, longitudinal cohorts, burden-of-disease analyses, and administrative healthcare utilization data suggests that these health impacts may persist beyond acute exposure periods (3, 5, 6). In the case of the Hebei Spirit oil spill, healthcare utilization patterns demonstrated sustained, specialty-specific deviations from baseline, consistent with prolonged health and healthcare system disruption following large-scale environmental disasters (5, 6, 7).

While causal inference is limited by the observational and ecological nature of the available data, the convergence of findings across diverse exposure settings strengthens confidence that environmental stressors are linked to both immediate and longer-term population health burdens (3, 6, 8). Beyond these evidence-based findings, the results highlight important considerations for public health planning and environmental policy. Strengthening environmental exposure monitoring, incorporating health impact assessment into disaster response frameworks, and supporting long-term health surveillance in affected communities may help mitigate downstream health consequences (2, 8). In addition, policies aimed at reducing chronic pollutant emissions, particularly from coal-fired power plants, may offer meaningful opportunities to lessen preventable disease burden (8, 9, 10). These implications extend beyond the specific case studies examined here and underscore the relevance of proactive, preventive approaches to environmental health protection.

Several limitations should be considered when interpreting the findings of this study. First, the healthcare utilization analysis relied on aggregated administrative outpatient visit data, which reflect patterns of healthcare-seeking behavior rather than individual-level disease incidence or clinical severity. As a result, the analysis is subject to ecological inference constraints, and associations observed at the population level cannot be assumed to represent causal relationships at the individual level.

Second, the use of administrative healthcare data introduces potential reporting and classification biases. Changes in diagnostic coding practices, healthcare access, provider availability, or health-seeking behavior following environmental disasters may have influenced observed utilization patterns independently of true health effects. In addition, population displacement and temporary disruption of healthcare services may have contributed to underreporting or delayed presentation in certain medical specialties during the post-disaster period.

Third, findings derived from the Hebei Spirit oil spill case study in Taean, South Korea may have limited generalizability. The geographic containment of contamination, the structure of the national health insurance system, and the availability of comprehensive administrative data enabled detailed longitudinal analysis but may not be representative of other regions

with different environmental conditions, healthcare infrastructures, or disaster response capacities.

Finally, the absence of individual-level exposure measurements, demographic covariates, and longitudinal clinical outcomes limited the ability to adjust for confounding factors such as socioeconomic status, preexisting health conditions, and policy changes over time. Despite these limitations, the integration of administrative healthcare utilization data with epidemiologic and toxicologic evidence provides a contextual framework for understanding how large-scale environmental stressors may be associated with sustained population-level health and healthcare system impacts.

CONFLICT OF INTEREST

The author declares no conflicts of interest related to this work.

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