

Burden of disease attributable to the Hebei Spirit oil spill in Taean, Korea

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ABSTRACT

Objectives: We aimed to assess the burden of disease (BOD) of the residents living in contaminated coastal area with oil spill and also analysed the BOD attributable to the oil spill by disease, age, sex and subregion.

Design: Health impact assessment by measuring years lived with disability (YLD) due to an oil spill.

Setting: A whole population of a community affected by an anthropogenic environmental disaster and secondary health outcome data.

Participants: Based on the health outcome survey including 10 171 individuals (male 4354; female 5817), BOD of 66 473 populations (male 33 441; female 33 032) was measured.

Interventions: None. Observational study on the effect of a specific environmental health hazard.

Primary and secondary outcome measures: Using disability adjusted life year (DALY) method, BOD including physical and mental diseases was measured. For the BOD measurement, excess incidences of illnesses related to oil spill were estimated from the comparison of prevalence of the health outcomes between contaminated areas and reference area without contamination.

Results: YLD attributable to the oil spill were estimated to be 14 724 DALYs (male 7425 DALYs; female 7299 DALYs) for the year 2008. The YLD of mental diseases including post-traumatic stress disorder (PTSD) and depression for men were higher than that for women. The YLD for women was higher in asthma and allergies (rhinitis, dermatitis, conjunctivitis) than that for men. The effects of asthma and allergies were the greatest for people in their 40s, with the burden of mental illness being the greatest for those in their 20s. Proximity to the spill site was associated with increased BOD.

Conclusions: An oil spill near a coastline can cause substantial adverse health effects. As the health effects of hazardous pollutants from oil spills are long-lasting, close follow-up studies are required to identify chronic health effects.

INTRODUCTION

On 7 December 2007, the Hebei Spirit oil tanker spilled 12 547 kL (10 900 tons) of crude oil into the Yellow Sea, approximately 8 km away

ARTICLE SUMMARY

Strength and limitations of this study

- This is the first study to quantify the burden of disease (BOD) of a single environmental disaster.
- This study demonstrates that BOD is an objective and comprehensive metric for estimating and comparing the health effects of environmental hazards and disasters across different regions and time periods.
- To estimate excess incidence, we used prevalence data classified by distance from the contaminated coast, under the assumption that the farthest region, area 4, has not been affected by the oil spill and that the prevalence of diseases had been same across the whole study area before the accident because prevalence data recorded prior to the oil spill were not available.
- We did not consider long-term health outcomes such as cancers and chronic degenerative diseases mainly because of lack of data.

from the coast of Taean, Korea. This was the largest oil spill in the history of Korea. Spilled oil contaminated over 1000 km of the western coast of Korea including the Taean Coast National Park.¹ Crude oil contains various volatile organic compounds (VOCs), such as benzene, toluene, ethylbenzene, xylenes and polycyclic aromatic hydrocarbons (PAHs),² all of which are potential air-borne toxins. Certain VOCs, benzene in particular, are carcinogenic to humans and are associated with haematological cancer.³ Previous studies^{4–11} have reported that oil spills have caused adverse health effects for residents of contaminated areas and clean-up workers. Risk analyses revealed that more frequent clean-ups and greater exposure to oil are strongly associated with higher frequencies of psychological symptoms.^{8–11} Rodríguez-Trigo⁶ reported that participation in a major oil spill clean-up is associated with chromosomal damage, although they were unable to determine whether oil exposure itself caused the abnormalities.

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After the Hebei Spirit oil spill, more than 2 000 000 people (person-days), including over 1 200 000 person-days by volunteers, participated in clean-up activities during the first 7 months.¹ Among them were residents of Taean, a highly exposed group that experienced adverse health effects, including physical and psychological symptoms.^{4–12} Although many studies have reported positive relationships between oil spills and acute and chronic health impacts, there have been no studies quantifying the burden of disease (BOD) due to oil spills, which are necessary to assess the scale of health damage at the population level as well as the associated compensation costs.

Therefore, we sought to quantify the adverse health impacts of exposure to oil spills by applying the disability-adjusted life year (DALY) measure developed by the WHO. The DALY measures health gaps as opposed to health expectancies. It measures the difference between a current situation and an ideal situation where everyone lives up to the age of the standard life expectancy and in perfect health. The DALY is based on the premise that the best approach for measuring the BOD is to use units of time.¹³ The DALY method has been used to measure the BOD attributable to specific risk factors including environmental burdens of disease (EBD).¹⁴ This approach can be practical in that the estimated adverse health burden attributable to a risk factor can be compared with other BODs and the analyses of disease burdens by disease and region can inform policy prioritisation to mitigate adverse health effects for specific exposed populations.

The purposes of this study are to assess the BOD of the residents of the contaminated Taean coastal area due to the Hebei Spirit oil spill and to analyse the BOD by disease, age, sex and subregion.

METHODS

Study area and design

In September 2008, the Taean Environmental Health Center (TEHC) was established with the support of the Korean Ministry of Environment to monitor the effects of the Hebei Spirit oil spill on the health of the residents of the Taean coastal area. The TEHC first conducted health surveys on the residents, including the referent population, 1.5 years after the spill, establishing a cohort. Total of 10 171 residents living in the study area were surveyed including 9246 adults (male: 3849; female: 5397) and 925 students (male: 505; female: 420 persons). The survey included a comprehensive questionnaire designed to gather personal history on exposure and medical problems and a structured questionnaire to assess psychological health, and asthma

and physical and laboratory examinations of respiratory, cardiovascular, neurological and psychological systems.

The TEHC published its first report in 2010 after analysing the prolonged health effects for 1.5 years and demonstrated significant relationships between exposure concentrations and adverse health outcomes.¹⁵ To estimate the BOD caused by the Hebei Spirit oil spill, we obtained the survey data from the TEHC, which included disease, residence and demographic information. Residents in Taean County and some islands in neighbouring Boryeong County were included in the survey. The Boryeong islands were expected to be affected by the oil spill because the islands are located in the affected area based on the wind direction and tidal current at the time of the spill.¹⁶ Kim *et al*¹⁶ reported that the VOCs moved in a southeasterly direction, following the coastline from the accident point.

We classified the residents of Taean County and the Boryeong islands into five based on distance from the contaminated coastline and contamination level. Area 1 is less than 1.1 km away from the coastline adjacent to the accident location where the coastline was contaminated at a high level. Area 2 is 1.1–4.2 km away with no coastline, but was directly affected by atmospheric VOCs and PAHs due to the wind direction. Area 3 is 4.2–23 km away from the coastline with a moderately contaminated coastline and area 4 is more than 23 km from the contaminated coastline. We classified the Boryeong islands as a separate area. [Figure 1](#) shows the locations of the five study areas and five classified regions.

We assessed health outcome data regarding asthma, allergy (rhinitis, dermatitis, conjunctivitis) and mental disorders (post-traumatic stress disorder (PTSD) and depression) that were well documented by the TEHC.¹⁵ We focused on subchronic (duration of a few months) and chronic (over 1 year duration) adverse health effects of the Hebei Spirit oil spill, assessing prolonged health effects during a period of 1.5 years to estimate the BOD of the Hebei Spirit oil spill for the year 2008.

Estimation of BOD attributable to oil spill

To estimate the BOD attributable to the oil spill, we applied the DALY method. DALY is the sum of the life years lost due to disability and premature death.¹³ As there was no premature death identified as the direct effect of the oil spill until the TEHC published the first report in 2010, we included only years lived with disability (YLD).¹³ The YLD is calculated by using disease incidence and prevalence, onset age and duration of disability and disability weight (DW). The formula we utilised is as follows:

$$YLD = D \left\{ \frac{C_e^{ra}}{(r+\beta)^2} [e^{-(r+\beta)(L+a)} [-(r+\beta)(L+a) - 1] - e^{-(r+\beta)a} [-(r+\beta)a - 1]] + \frac{1-K}{r} (1 - e^{-rL}) \right\} \quad (1)$$

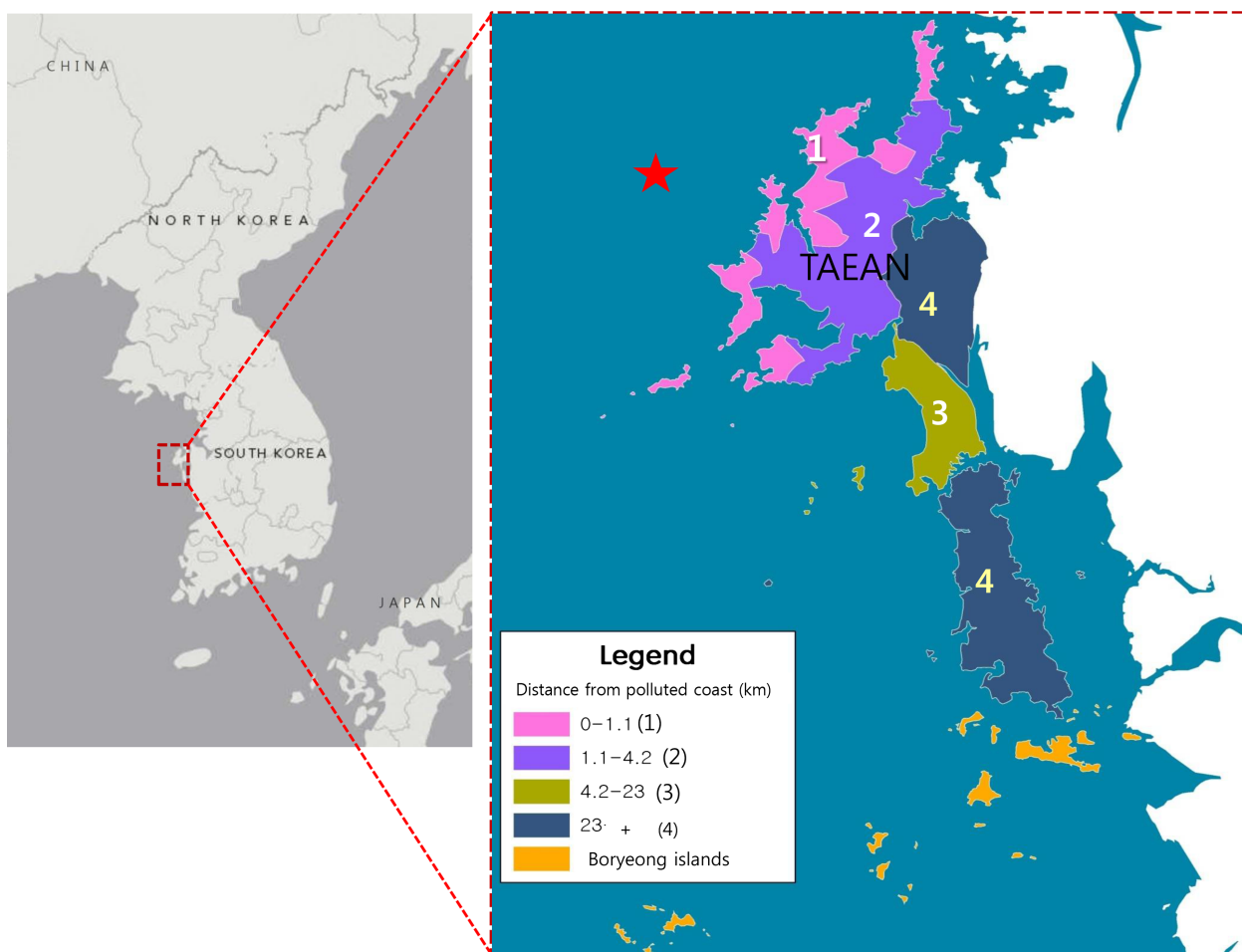


Figure 1 Study area and classification of affected regions. ★—accident site, about 8 km away from the Taean coastline.

where D is the disability weight; r the discount rate; a the age of onset of the disability; L the duration of the disability; β the parameter from the age weighting function and C the constant. We used 3% of discount rate and 0.04 and 0.0618 for β and C , respectively, as suggested by the WHO.¹³

Because there was no prevalence data recorded prior to the accident, we estimated excess incidences using prevalence data from the TEHC under the following assumptions. We first assumed that residents living in area 4 had no negative health consequences due to the oil spill and used this as the baseline prevalence. Area 4 was assumed to be the reference area, not only because the area might not be impacted by the oil spill directly as it is far from the contaminated coastline but also because residents in area 4 rarely participated in the clean-up works. Second, we assumed that the prevalence of oil spill-related diseases in the whole study area had been same prior to the accident. We then estimated excess incidences using prevalence differences between area 4 and the other areas stratified by area, age, sex and disease using following formula:

$$EI_{ij} = \sum \text{POP}_i \times (\text{Pr}_{ij} - \text{Pr}_{cj}) \quad (2)$$

where, EI_{ij} is the excess incidence of region i and disease j ; POP_i the population of region i ; Pr_{ij} the prevalence of region i and disease j ; Pr_{cj} the prevalence of control region and disease j .

The duration of disability and the average onset age were calculated using the DISMOD II model¹⁷ for PTSD, rhinitis, dermatitis and conjunctivitis based on prevalence data from the TEHC and the mortality rate of South Korea¹⁸ by age, sex and disease. For asthma, the results of the Victoria, Australia study¹⁹ were used.

DWs for each disease were measured following a method previously used by the Global Burden of Disease group¹³ and the Dutch Disability Weights Group.²⁰ A panel that included 12 health and medicine specialists was convened. Eleven indicator conditions including asthma, stomach cancer, diabetes, dementia, major depression, appendicitis, thyroid cancer, hepatitis A, otitis media, atopic dermatitis and common cold were measured using the person trade-off (PTO) method. The 11 indicator conditions were selected in accordance with a previous study on Korean DW.²¹ That is, we considered that they should be meaningful in public health and relatively popular diseases, while distributing the whole DW range (0–1) evenly.²¹ A facilitator first explained the method and then led the discussion to

determine the PTO value of each participant. The discussion was repeated twice. Then, the visual analogue scale (VAS) method was applied to obtain DWs for 118 conditions including asthma, rhinitis, dermatitis, conjunctivitis, PTSD and depression used in this study. Intermethod reliability was confirmed between PTO and VAS using 11 indicator conditions, which showed fairly high consistency (Spearman's correlation coefficient 0.966, p value <0.001). Reliability was confirmed by test-retest after 3 weeks by seven specialists and obtained fairly high consistency (Spearman's correlation coefficient 0.973, p value <0.001).

Finally, we estimated YLD caused by the Hebei Spirit oil spill utilising the estimated excess incidence attributable to the oil spill, DW and the onset age and duration of disability by disease, age, sex and area.

RESULTS

Summary of the characteristics of the study area

The populations of Taean County and the Boryeong islands were 63 053 individuals (male 31 636; female 31 417) and 3420 individuals (male 1805; female 1615) in 2008, respectively. Classified by area, 8348 (13%), 11 272 (17%), 4597 (7%), 38 836 (58%) and 3420 (5%) residents lived in areas 1–4 and the Boryeong islands, respectively. Area 4, the reference area, was the most populous because it includes a town centre. The largest age group consisted of individuals in their 50s, with individuals in their 40s, 50s and 60s comprising 45% of the total population (data are presented in online supplementary table S1).

A total of 10 171 residents living in the study area participated in the TEHC survey. Among them, 4354 (42.8%) and 5817 (57.2%) residents were men and women, respectively. Individuals under 15 years of age, 15–65 and over 65 years of age comprised 7.2%, 48.0% and 44.8% of the population, respectively. Residents of area 1 participated in clean-up work for an average of 122 days and residents of areas 2 and 3 and the Boryeong islands participated for averages of 50, 36 and 100 days, respectively.¹⁵ Table 1 shows the prevalence of disease related to the current study by disease, sex and area derived from a survey of 9246 adult (over 19 years old) residents. For young people under 19 years old, we used results from 925 school students (male 505; female 420) living in the study area. More details including prevalence by age are shown in data in online supplementary table S2.

Estimated BOD due to oil spill

Excess incidence attributable to the oil spill

The excess incidence of disease, estimated from the available prevalence data, caused by the oil spill varied by area, sex and disease (table 2). Excess incidence by age is shown in data in online supplementary table S3. There were additional incidences of asthma (2088: 989 male; 1099 female), rhinitis (3625: 1855 male; 1770

female), dermatitis (1976: 962 male; 1014 female), conjunctivitis (2992: 1365 male; 1627 female), PTSD (2681: 1300 male; 1381 female) and depression (2326: 1370 male; 956 female) in areas 1–3 and the Boryeong islands.

Area 1 had the highest additional incidences for all diseases, while area 3, a relatively less affected area than areas 1 and 2, showed the lowest additional incidences for all diseases.

Disability weight

The VAS results showed that the DW for stomach cancer (stage 4) was the highest at 0.909 and that the DW for upper respiratory infection was the lowest at 0.065, of a total of 118 conditions surveyed. Among the 118 conditions, DWs for diseases examined in this study are shown in table 3. We used the DW of mild intermittent asthma, 0.222, to represent asthma, because the prevalence of asthma in this study area was estimated using survey results following the modified International Study of Asthma and Allergies in Childhood and most cases of asthma were not severe.¹⁵

BOD due to oil spill

Figure 2 presents the YLD according to disease, sex and age group. The YLD for asthma, allergic rhinitis, dermatitis, conjunctivitis, PTSD and depression were approximately 6138 DALYs, 2420 DALYs, 1417 DALYs, 18 DALYs, 2869 DALYs and 1862 DALYs, respectively. The total YLD attributable to the Hebei Spirit oil spill for the year 2008 was 14 724 DALYs. The YLD for men was 7425 DALYs and for women was 7290 DALYs. The YLD for men for PTSD and depression were higher than for women and the YLD for women was higher in asthma and allergies than for men (more details are shown in data in online supplementary table S4). Among the included diseases, the YLD for asthma was the highest. The YLD for asthma and allergies was the highest for residents in their 40s and the YLD for mental disease was the highest for residents in their 20s.

DISCUSSION

The total YLD attributable to the Hebei Spirit oil spill was estimated at 14 724 DALYs for the year 2008. Asthma was found to represent the most prominent disease burden (6138 DALYs) among the six diseases, followed by PTSD and rhinitis. The asthma burden of 6138 DALYs in the study area can be translated to 9233 DALYs/100 000 individuals or 6.5 times higher in contrast to the total burden of asthma for South Korea of 1418 DALYs/100 000 individuals.²² Kim *et al*²³ estimated the prevalence and economic costs of allergic rhinitis in South Korea for 2007 and reported that a total of 4 068 517 people were identified as having allergic rhinitis. The direct cost was \$223.7 million and the lost productivity was estimated to be \$49.3 million, for a total

Table 1 Prevalence of diseases related to this study (%)

Disease	Area 1*		Area 2		Area 3		Area 4		Boryeong Islands	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Asthma	22.0	20.4	15.4	11.7	9.6	10.4	8.7	7.6	23.8	27.9
Allergy										
Rhinitis	41.4	34.6	25.2	20.2	23.9	10.6	20.2	15.9	42.6	40.2
Dermatitis	19.6	25.0	5.1	6.1	9.4	4.7	2.4	4.4	10.1	15.0
Conjunctivitis	32.0	38.7	12.6	12.6	13.2	9.0	9.2	10.0	17.0	24.5
Mental disease										
PTSD	32.9	34.6	7.0	7.1	2.9	3.1	4.6	3.2	10.8	13.5
Depression	23.3	29.9	8.8	14.8	8.8	14.0	5.3	11.6	21.3	25.2

*Area 1: less than 1.1 km away; area 2: 1.1–4.2 km away; area 3: 4.2–23 km away; area 4: more than 23 km from the contaminated coastline. PTSD, post-traumatic stress disorder.

economic burden of \$272.9 million in 2007. Applying this method to the current study, with an excess incidence of 3625 persons, the cost of additional allergic rhinitis due to the oil spill is roughly estimated to be \$243 170 for 1 year (2008). These results indicate that oil spills near coastlines can cause considerable adverse health effects and that the summation of disease burden should not be neglected, although the size of the population affected may be small.

The health impacts of oil spills on residents of contaminated areas vary by age, sex and region. Approximately 1 year after the accident, the burden of mental disease attributable to the oil spill was higher in men than in women, whereas the burden of allergies was higher in women than men. The most heavily impacted area, area 1, comprised the majority of the BOD attributable to the oil spill. For example, about 60% of the additional incidences of disease occurred in area 1, less than 1.1 km from the contaminated coast, with 22% in area 2 and 6% in area 3. Critical health effects of oil spills are more likely to affect clean-up workers due to higher and repeated exposures to hazardous pollutants. Residents of area 1 participated in clean-up work for an average of 122 days and residents of areas 2 and 3 participated for averages of 50 and 36 days, respectively. Previous studies on the acute health

impact of oil spills^{4–6} also reported that more frequent and greater exposure to clean-up activities was strongly associated with a higher occurrence of symptoms, including acute and chronic health outcomes.

To estimate the excess incidences of illnesses caused by an oil spill, we used prevalence data classified by distance from the contaminated coast, under the assumption that the farthest region, area 4, was not affected by the oil spill and that the prevalence of diseases had been same in all study areas before the accident, which is one of the limitations of this study. These assumptions were used because real data describing disease prevalence before and after the oil spill were not available. Residents in area 4, the reference area, had very little participation in the clean-up efforts, which could account for differences in disease prevalence between area 4 and other areas. In addition, 72 h after the oil spill, the downwind direction changed from the southeast to the west and as a result, volatile components did not move further inland.¹⁶ The benzene concentrations in the atmosphere after the Hebei Spirit oil spill simulated in our previous study²⁴ also showed that concentrations reduced rapidly with distance from the contaminated coastline. Benzene concentrations over 0.1 ppm were not detected at the area more than 13 km from the spill site. Therefore, the assumption that area 4

Table 2 Excess incidence caused by the oil spill (unit: number of persons)

Disease	Area 1*		Area 2		Area 3		Boryeong Islands		Total	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Asthma	473	449	241	231	53	97	222	322	989	1099
Allergy										
Rhinitis	839	729	453	481	209	207	353	354	1855	1770
Dermatitis	606	687	146	158	94	32	116	138	962	1014
Conjunctivitis	857	1040	294	214	101	183	113	190	1365	1627
Post-traumatic stress disorder	1092	1054	133	222	0†	0	76	106	1300	1381
Depression	838	581	266	169	65	57	201	149	1370	956

*Area 1, less than 1.1 km away; area 2, 1.1–4.2 km away; area 3, 4.2–23 km away; area 4, more than 23 km from the contaminated coastline
†No difference between area 3 and reference area.

Table 3 Disability weights used in the current study

Disease	Stage	Disability weight
Asthma	Mild intermittent	0.222
	Mild persistent	0.291
	Moderate persistent	0.510
	Severe persistent	0.715
	Very severe persistent	0.836
Allergy	Rhinitis	0.205
	Dermatitis	0.132
	Conjunctivitis	0.212
Post-traumatic stress disorder		0.533
Depression		0.219

was not affected by the oil spill is reasonable. Kim *et al*²⁵ reported that the prevalence of rhinitis in Korean population was 16.4%, 24.7% and 21.7% in 20–35, 36–50 and older than 50 age group, respectively, while that of area 4 adults was 15.8% and 17.9% in 19–49 and over 50 age group, respectively, showing slightly lower prevalence than whole Korean population.

It is possible that PTSD and depression may overlap. According to a previous cross-sectional study of psychological disease in Korea, about 8.5% of depression is accompanied by PTSD.²⁶ This indicates that the

estimated disease burden may have been overestimated. For this reason, we did not include anxiety in our analyses, although prevalence data for anxiety were available because about 15% of anxiety is accompanied by depression in Korea.²⁶

Although the PAHs and VOCs in spilled oil can cause haematological cancer, lung cancer and stomach cancer,⁶ we did not assess the incidences of any cancers due to the lack of data. The TEHC analysed the urinary malondialdehyde (MDA) and 8-hydroxy-2'-deoxyguanosine (8-OHdG) levels of residents in the contaminated area, as oxidative stress indices and the TEHC found that the urinary MDA and 8-OHdG concentrations of the residents living in area 1 were much higher than in other areas. The average urinary MDA concentration of residents in area 1 was 5.42 (SD=3.14) $\mu\text{mol/g Cr}$, whereas that of other areas was 3.83 (SD=2.58) Cr .¹⁵ The average 8-OHdG concentration for area 1 was 6.84 (SD=3.84) $\mu\text{g/g Cr}$, whereas that of other areas was 4.67 (SD=3.00) $\mu\text{g/g Cr}$. Previous studies reported that oxidative DNA damage is associated with increased risk of cancer, including haepatocellular carcinoma, lung cancer and breast cancer and thus the MDA and hepatic 8-OHdG levels are useful as markers to identify subjects at extremely high risk.^{27–29} The increased urinary MDA

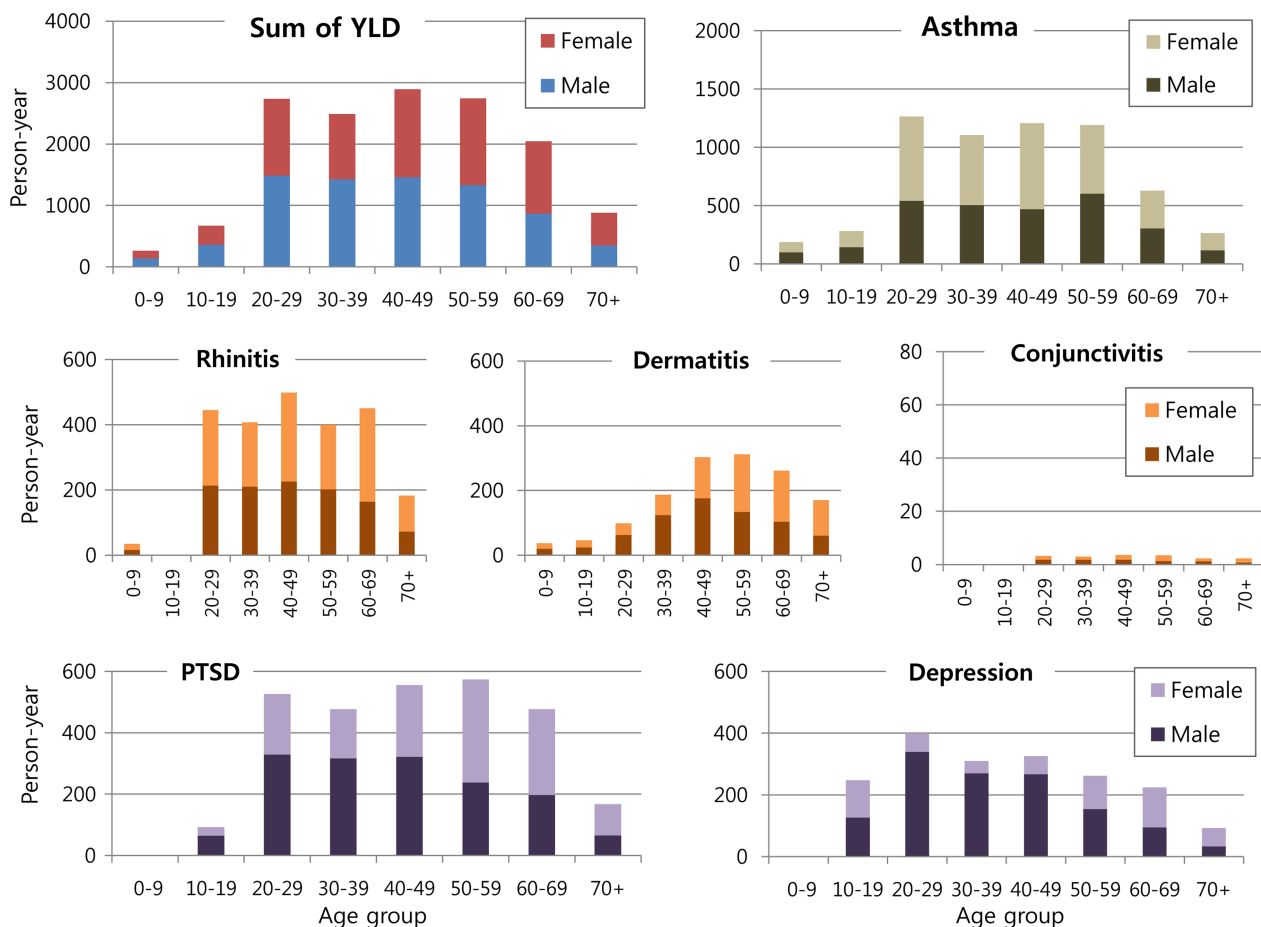


Figure 2 Burdens of disease attributable to the Hebei Spirit oil spill by disease, age and sex. YLD, years lived with disability; PTSD, post-traumatic stress disorder.

and 8-OHdG concentrations in the residents in this study area may be useful to track the risks for excess cancers in the future. By monitoring more long-term effects, the BOD imposed by these diseases may be quantified and added to the results of this study.

This is the first study to quantify the BOD of a single environmental disaster. The EBD of the current study was estimated for a highly exposed population after a single event. This study demonstrates that BOD is an objective and comprehensive metric for estimating and comparing the health effects of environmental hazards and disasters across different regions and time periods. One of strengths of this study is that we measured BOD attributable to oil spill by subregion as well as age and sex including physical and mental health outcomes, which can help to prioritise the health policies and mitigation efforts to reduce adverse health effects.

CONCLUSIONS

Oil spills near coastlines can cause considerable adverse health effects. The BOD for 1 year for the residents living near contaminated coastal areas is significant and is related to proximity to the spill as well as participation in clean-up efforts. Asthma and PTSD were found to comprise the most prominent disease burden in the contaminated areas. The health impacts of oil spills on residents vary with age, sex and region implying that rehabilitation policy should be community-specific.

As the health effects of hazardous pollutants from oil spills are long-lasting, close follow-up studies are required to estimate the cumulative disease burden of oil spills based on the identification of long-term health effects.

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Contributors YMK prepared a manuscript of this article and conducted statistical analysis. JHP supervised the technical aspect of estimation of burden of disease and conducted a survey on the disability weight. KC conducted statistical analysis and participated in the discussion section. SRN provided data and participated in the discussion of the outcome. YHC provided a framework of interpretation of findings and participated in the discussion of the outcome. HKC designed the study, supervised the estimation of exposure and health outcome and edited and finalised the article.

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Competing interests None.

Patient consent Obtained.

Ethics approval Taean Environmental Health Center.

Provenance and peer review Not commissioned; externally peer reviewed.

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