

BMJ Open Health effect research on Hebei Spirit Oil Spill (HEROS) in Korea: a cohort profile

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ABSTRACT

Purpose The Hebei Spirit Oil Spill occurred on 7 December 2007 and resulted in the spillage of 12 547 kl of crude oil on the coastline near Taean. Historically, this was the largest oil spill in Korean water. The health effect research on Hebei Spirit Oil Spill (HEROS) is a prospective cohort study that aimed to evaluate the long-term health effects of oil spill exposure on residents in the affected community.

Participants The Taean Environmental Health Center initially enrolled adults, adolescents and children living in Taean in 2009 and 2010. Follow-up surveys of participating adults and children were conducted every other year. By 2017, a total of 9585 adults and 2216 children and adolescents were enrolled. Of these, 294 adults and 102 children and adolescents were included in all subsequent surveys.

Findings to date Children who lived closer to the oil spill site exhibited a lower level of pulmonary function and higher prevalence of allergic rhinitis, than those who lived further away from the oil spill site. Adults who lived in a highly exposed area or participated in clean-up work had higher urine levels of the oxidative stress biomarkers malondialdehyde and 8-hydroxydeoxyguanosine. Changes in haematological parameters during a 3-year period were observed in residents of both sexes in highly exposed areas, in addition to increases in respiratory diseases and mental health problems in female and male participants, respectively.

Future plans The findings of this study will better enable policy makers to develop environmental health policies intended to prevent adverse health effects in residents of communities affected by oil spills, as well as policies regarding the management of future oil accidents. The HEROS study will continue to follow participants in future and will be updated to enable an investigation of long-term health effects.

INTRODUCTION

On 7 December 2007, the Hong Kong-registered crude oil tanker Hebei Spirit was struck by a crane barge operated by Samsung Heavy Industries while anchored 5 miles offshore of Taean County on the west coast of the Republic of Korea (longitude, 126.058806; latitude, 36.893047).¹ The Hebei Spirit was carrying ~302 640 kl (263 944 tons) of crude

Strengths and limitations of this study

- The health effect research on Hebei Spirit Oil Spill (HEROS) study is a prospective panel study to investigate the long-term health effects of an oil spill.
- The HEROS study includes susceptible populations of community residents such as children and pregnant women.
- The HEROS study has stored participants' blood and urine samples collected since 2009.
- This study did not include coast guard or military personnel who were assumed to be highly exposed due to extensive involvement in clean-up work.

oil and as a result of the collision, ~12 547kl (10 900 tons) of crude oil were spilled into the sea.² As of 10 October 2008, a total of 2 132 322 person-days were dedicated to clean-up work, which involved 563 896 residents who had been living in the affected area, 1 226 730 volunteers who came from all over the country to participate in the clean-up, 152 695 military personnel, 32 356 police officers, 17 460 coast guard personnel, 55 838 professional workers, 6663 members of the Korea Marine Environment Management Corporation and 76 684 local civil servants.² The spilled crude oil contained three types of source oil: Iranian Heavy, Kuwait Export Crude and UAE Upper Zakum and therefore comprised various proportions of volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons and heavy metals.³

Although the occurrence of previous large-scale oil spills and the associated effects and restoration efforts were previously determined in various studies, most studies focused on consequences to the ecosystem. By contrast, only a few studies focused on human health.⁴

A series of previous studies reported on the adverse health effects of acute exposure to the Hebei Spirit Oil Spill (HSOS). Notably, children who lived or attended schools near

the contaminated coast, participants engaged in clean-up work, workers who lacked protective equipment during the early clean-up phase, and those with fishery-related occupations experienced both negative physical^{5–12} and psychological short-term health outcomes.^{13–16}

However, the long-term health effects of a few oil spills, including the Prestige oil spill in Spain,¹⁷ Deep-water Horizon (DWH) oil spill in the USA¹⁸ and HSOS in Korea,¹⁹ have been investigated, and all these studies reported adverse outcomes.²⁰ The Prestige study reported that chromosomal damage occurred for as long as 6 years in fishermen exposed to the oil spill²¹ and that fisherman who participated in clean-up work experienced respiratory symptoms up to 5 years after the oil spill.²² Recently, DWH studies have shown associations between the following: oil response and clean-up work and an increased prevalence of depression and post-traumatic stress (PTS) disorder²³; oil exposure and nonfatal myocardial infarction²⁴; residential proximity to the spill and duration of clean-up work and increased risk of heart disease events up to 5 years after the spill²⁵; and high exposure to burning oil or gas in decontamination workers, compared with unexposed workers, and reduced lung function 1–3 years after exposure.²⁶

Most previous studies focused on the health effects on clean-up workers except for the Women and Their Children's Health study²⁷ and Gulf Resilience on Women's Health study,²⁸ both related to the DWH oil spill. The present study named health effect research on Hebei Spirit Oil Spill (HEROS) is one of only a few oil spill cohort studies focused on a residential population that includes children and pregnant women living in the affected areas. This paper describes the design and structure of the HEROS, the main outcome, findings to date and prospective plans.

COHORT DESCRIPTION

Study design and setting

The HEROS study is both a prospective cohort and panel study designed to investigate the effects of crude oil exposure on the health of local community residents. The study has been conducted by the Taean Environmental Health Center (TEHC) in cooperation with the County Public Health Hospital and two university hospitals near Taean, Dankook University Hospital and Soonchunhyang University Hospital. Eligible adults were those aged 18 years or older who lived in Taean County and agreed to participate the survey. Eligible children and adolescents were those who attended kindergarten or school within 20 km of the accident site (4 kindergarten centres, 17 elementary schools, 4 middle schools and 1 high school). The population of Taean in 2016 was 63 900 residents (18 272 and 45 628 in the coastal and inland areas, respectively).²⁹ The baseline survey was initiated in August 2009, 21 months after the oil spill accident and 8 months after the completion of all clean-up activities. After the baseline survey, follow-up surveys were conducted every other

year: adults in 2010, 2012, 2014 and 2016, and children in 2011, 2013, 2015 and 2017 (figure 1).

Cohort participants and follow-up

The study population comprised 16.5% (10 418/63 095) of all Taean residents in 2009,²⁹ from where all participants were recruited. At the baseline survey, a total of 9246 adults (men: 3849, women: 5397) and 1172 children and adolescents (children, boys: 351, girls: 345; adolescents, boys: 303, girls: 164) were recruited. Before enrolment, the village leaders asked their residents about participating in the study. The adults, including pregnant women, who agreed to participate, visited the study centre and underwent a health examination. Children and adolescents submitted informed consent forms signed by their parents or guardians to their class teachers. A vehicle carrying the necessary medical equipment then went to the kindergarten centres and schools of participating children and adolescents to complete their health examinations.

By 2017, a total of 9585 adults from the community and 2216 children and adolescents from 21 institutions (4 kindergartens, 12 elementary, 4 middle and 1 high schools) had participated (figure 1). Adult participants were contacted using the telephone numbers obtained during the first baseline survey in 2009 to request their follow-up participation. If the participant's contact information changed, we contacted the village leader for updated information. The follow-up focused on populations in areas of high exposure with a small population of participants from areas of low exposure. The percentage of participants from areas of high exposure was 18.8% (1741/9246), 93.2% (1172/1257), 94.4% (1093/1158), 76.7% (615/802) and 90.1% (1149/1275) at the baseline, second, third, fourth and fifth surveys, respectively; the remaining participants were from areas of low exposure (figure 2). Children and adolescents were contacted for follow-up by sending an official letter of cooperation to the principals of schools where more than 10 students had participated in the baseline survey. The school sent an invitation letter to the family members of each child enrolled, and the researchers then received individual consent forms from families that wished to participate. For participants who had advanced to a higher-level school, the researcher individually sought participation using the contact information obtained prior to graduation. A total of 294 adults and 102 children and adolescents participated in all 5 rounds of the survey from 2009 to 2017. Participation rates among subjects who were invited to participate the study have ranged from 75% to 90% in each survey.

Furthermore, 85 women who were in the first trimester of pregnancy at the time of the oil spill were recruited and their children have been followed since birth in subsequent surveys. We used the same protocol as the Mothers and Children's Environmental Health (MOCEH) study and used the original MOCEH study

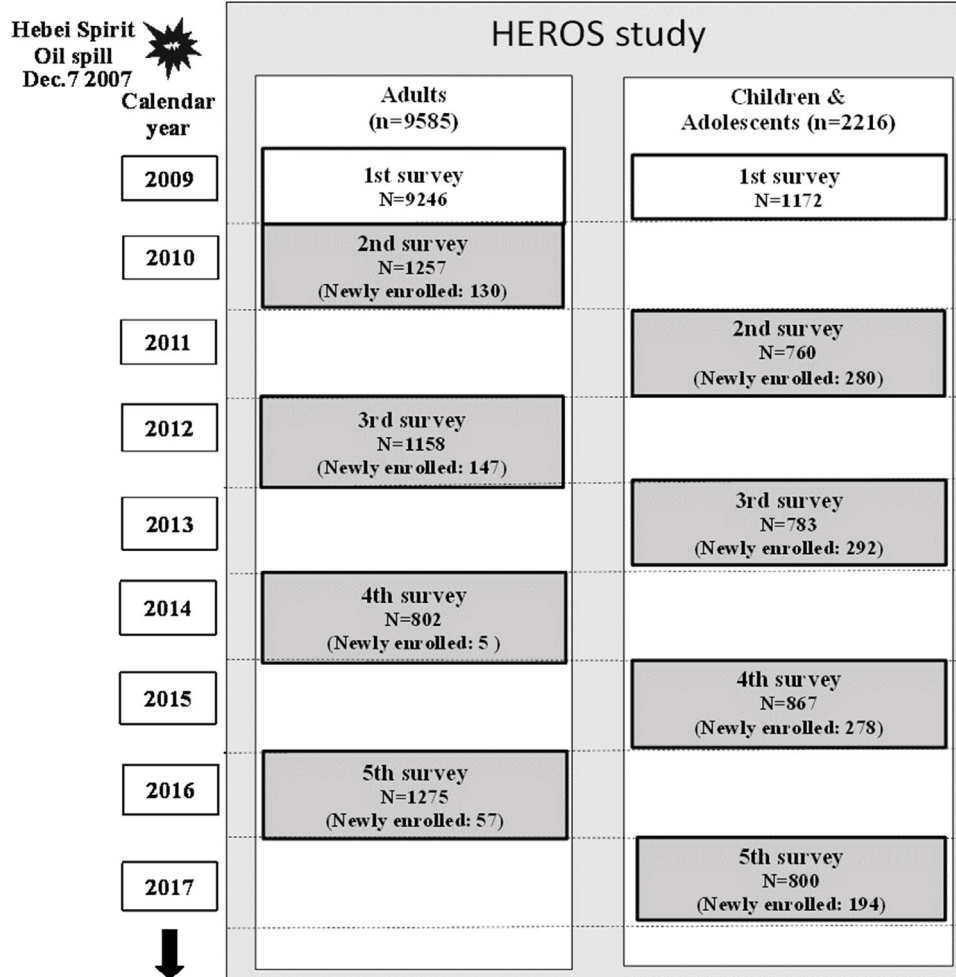


Figure 1 Flow diagram of baseline and follow-up for Health Effect Research on Hebei Spirit Oil Spill (HEROS) study after the Hebei Spirit Oil Spill, Korea. Newly enrolled subjects were those who lived in the Taean area at the time of oil spill but had not participated in previous surveys.

participants as a control population. MOCEH is a multi-centre cohort of pregnant women (N=1620) recruited between 2006 and 2010 in Korea.³⁰ The TEHC collected biospecimens, obtained information of oil exposure and sociodemographic characteristics by questionnaire

and assessed birth outcomes and neurodevelopment at 6 months and 1, 2, 3, 4 and 5 years of age in 72, 72, 60, 49, 50 and 39 children, respectively. In 2015 and 2017, 27 and 30 children successfully completed follow-up, respectively.

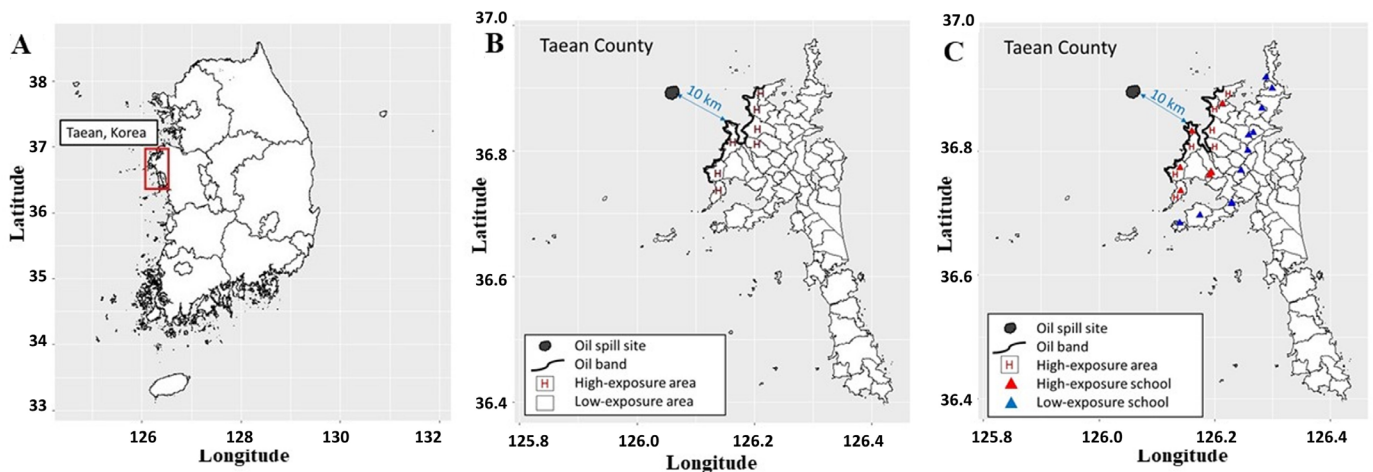


Figure 2 Map of the study area for Health Effect Research on Hebei Spirit Oil Spill study, Korea. (A) South Korea; (B) study area for adults; (C) study area for children and adolescents in Taean county.

Informed consent was obtained from each participant, or the parent or guardian of participating children younger than 13 years of age, prior to enrolment in each survey.

Questionnaire survey

The questionnaire was administered at each survey using one of two methods: via an interview conducted by trained interviewers for elderly (>60 years) adults, or as a self-administered questionnaire for younger adults (≤60 years) and the parents or guardians of children and adolescents. The questionnaire survey required 30–60 min to complete. Participants were asked to respond to questions regarding sociodemographic characteristics (age, sex, education, occupation, household income and marital status), lifestyle habits (alcohol intake, smoking, secondhand tobacco smoke exposure (SHS) and exercise), residential environment (eg, distance to industrial facilities, traffic volume), dietary habits (food frequency questionnaire, fish consumption), participation, time and duration of clean-up work (monthly, daily), use and type of protective equipment (monthly, daily) and place of residence at the time of the accident and the residential duration.

In adults, mental health factors such as depression, PTS and anxiety were assessed using standardised scales. Depression was assessed using the Korean version of the Center for Epidemiologic Studies Depression Scale.³¹ PTS was subsequently translated into the Korean language and validated.³² To assess anxiety symptoms, the Korean version³³ of the State-Trait Anxiety Inventory developed by Spielberger *et al* was used.³⁴ In children, depression and anxiety symptoms were assessed using the Korean version³⁵ of the Children's Depression Inventory, developed by Kovacs,³⁶ and the State-Trait Anxiety Inventory for Children.³⁷ Furthermore, attention deficit/hyperactivity disorder in children was measured using the Korean version of Attention Deficit Hyperactivity Disorder Rating Scale.³⁸ The modified Korean version of the International Study of Asthma and Allergies in Childhood questionnaire was used to evaluate asthma and allergic disease (table 1).³⁹

Exposure assessment and classification

Exposure to crude oil was defined as high versus low using three criteria: distance from the oil spill,¹⁵ duration and/or intensity of clean-up work with consideration of the use of protective devices,¹⁹ and ambient concentration of VOCs at home at the initial time of accident calculated by the simulation modelling.⁴⁰

In terms of adults, the high exposure area was defined as a coastal region of the smallest administrative unit that was contaminated with a thick layer of oil in the initial stage of the accident; all other areas in Taean county were defined as the low exposure area (figure 2A and B). For children and adolescents, the exposure status was dichotomously grouped using a distance cut-off (3 km) between their school and the heavily contaminated coastline

(figure 2C); 7 schools were classified as high exposure (5 elementary, 1 middle and 1 high school) and 15 as low exposure (4 kindergartens, 8 elementary and 3 middle schools).

The duration of clean-up work with consideration of the use of protective devices was also evaluated as an exposure index. The extensive clean-up along the coastline took ~11 months after the HSOS to complete, and residents of the affected areas were given priority to be employed as paid workers to clean up oil spills if desired. Most of the local residents had worked in the fishing and tourism industries which were almost totally destroyed due to the oil contamination of the accident. Compensation by insurance took several years due to the lengthy claim analysis and damage assessment processes. Furthermore, the public relief measures were not enough for most of the affected residents to maintain their livelihoods. Participants who were employed in clean-up efforts received a brief education on the job duties and protection before starting the work. Because this was the first large-scale oil spill in Korea, the amount of personal protective equipment such as clothing, gloves, masks and boots provided by the local government was insufficient to provide it to all workers, with supplies running out in the first several hours of the day of the accident. Accordingly, some participants had to use personal items as protective equipment, which may not have been effective for protection against oil exposure, while other workers did not wear any protective equipment.⁶ The clean-up work conducted by participating residents involved manual removal using absorptive materials. Air compressors were applied to a very limited area by professional workers, and oil dispersants were applied only in the seawater at a distance from the coast by the Korean Coast Guard; these individuals were excluded from this cohort.

The airborne concentration of VOCs at the time of the accident was simulated by the California Puff (CALPUFF) air dispersion model integrated with the weathering algorithm. Each participant's exposure level was calculated by using the residential address linked with the geographical information system.⁴⁰

Health examination and biospecimen collection

The health examination survey at baseline was conducted at the TEHC and County Hospital in collaboration with the two nearby university hospitals. In follow-up surveys, all study participants visited the TEHC and County Hospital to receive a health examination based on a standardised protocol. In all participants, the height, weight, waist circumference, blood pressure and heart rate variability were assessed through medical examinations. A skin prick test to identify specific allergens in underlying allergic diseases, exhaled nitric oxide test and lung function test (spirometry) were performed.⁴¹

Subgroups of participants who were selected or screened by the questionnaire interview and/or other examinations were also subjected to a colour vision test, vibration sense test and methacholine challenge test.

Table 1 Overview of measurements and variables collected at baseline and follow-up surveys and examinations for Health Effect Research on Hebei Spirit Oil Spill study, Korea

	Survey wave				
	First baseline	Second	Third	Fourth	Fifth
Calendar year of survey					
Adults	2009	2010	2012	2014	2016
Children and adolescents	2009	2011	2013	2015	2017
Measurement					
Questionnaire					
Sociodemographic data					
Age, sex, household income*	v		v	v	v
Education	v	v	v	v	v
Marital status*	v		v		
Occupation*	v	v	v	v	v
Exposure to oil spill					
Participation of clean-up work	v		C	v	v
Days of working on clean-up	C		v	v	v
Wearing protective devices			C	v	v
Distance from the oil spill site	v	v	v		
Health behaviour					
Self-reported smoking and alcohol habit, SHS and physical activity	v	v	v	v	v
Dietary habit (FFQ and fish consumption)	v		v	v	v
Medical history					
Disease history	v	v	v	v	v
Current status of disease treatment	v	v	v	v	v
Mental health (CES-D, PTSD, CDI†, ADHD†)	v	v	v	v	v
Allergic disease					
ISAAC questionnaire†	v	v	v	v	v
Health examination					
Height, weight and blood pressure	v	v	v	v	v
Waist circumference†	v	v	v		
Exhaled NO			v	v	
Methacholine challenge test†	P	P			
Lung function test (FVC, FEV ₁ and FEV ₁ /FVC)	v	v	v	v	v
Skin prick test (D.P, D.F, Grass, Tree and Cat)	v	v	v	v	v
Bone mineral density*	v	v	v		
Heart rate variability*	v	v	v	v	v
Colour vision test and vibration sense test*	P	P			
Blood test					
CBC	v	v	v	v	v
BUN and creatinine	v	v	v	v	v
AST, ALT, γ -GTP	v	v	v	v	v
Cholesterol (total, HDL), triglyceride	v	v	v	v	v
hs-CRP	v	v	v	v	v
HbA1C	v	v	v	v	v
Biomarkers					
Hair					
Not determined				C	C
Blood					

Continued

Table 1 Continued

	Survey wave				
	First baseline	Second	Third	Fourth	Fifth
Heavy metals (Pb, total Hg and Mn)	v	v	v	v	v
Urine					
VOCs metabolites (<i>t,t</i> - muconic acid, mandelic acid)	v	v	v		
PAHs metabolites (2-naphthol, 1-hydroxypyrene)	v	v	v		
Heavy metals (inorganic Hg and Cd)	v	v	v	v	v
Oxidative stress biomarkers (MDA and 8-OHdG)	v	v	v	v	

*Measured in adults only.

†Measured in children only.

ADHD, attention deficit/hyperactivity disorder; ALT, alanine aminotransferase; AST, aspartate aminotransferase; BUN, blood urea nitrogen; C, conducted only in children; CBC, complete blood cell count; CDI, Children's Depression Inventory; CES-D, Center for Epidemiologic Studies Depression Scale; D.F, *D. farinae*; D.P, *D. pteronys*; FEV₁, forced expiratory volume in one second; FFQ, food frequency questionnaire; FVC, forced vital capacity; γ -GTP, γ -glutamyltransferase; HDL, high-density lipoprotein; HbA1C, glycosylated haemoglobin; ISAAC, International Study of Asthma and Allergies in Childhood questionnaire; MDA, malondialdehyde; 8-OHdG, 8-hydroxy-2-deoxyguanosine; P, conducted only in selected participants; PAHs, polycyclic aromatic hydrocarbons; PTSD, post-traumatic stress disorder; SHS, secondhand tobacco smoke exposure; VOCs, volatile organic compounds; hs-CRP, high-sensitivity C reactive protein; v, conducted in all participants.

Participants were instructed to collect a urine sample after a 12-hour fast between dinner and the next morning and to store the urine sample in the refrigerator. Participants visited the study centre to deliver the collected urine samples, which were divided into aliquots and immediately stored in a freezer at -20°C until analysis. Blood samples were also obtained from participants after a 12-hour fast and stored in a freezer at -80°C . Approximately 100 mg of hair was collected from each participant and stored in a clean polyethylene bag. These hair samples have not yet been analysed.

Analysis of biomarkers

A list of biomarkers analysed in the study are shown in table 1. Biomarkers measured in urine samples included *t,t*-muconic acid, mandelic acid, hippuric acid, 2-naphthol (2-NAPH), 1-hydroxypyrene (1-OHP), mercury and cadmium, as well as malondialdehyde (MDA) and 8-hydroxydeoxyguanosine (8-OHdG). The level of urinary MDA was determined by measuring the level of thiobarbituric acid-reactive substances using high-performance liquid chromatography with a fluorescence detector.⁴² The following parameters were measured in blood samples: complete blood cell counts (leucocyte count, erythrocyte count, haemoglobin, hematocrit), liver function tests (aspartate aminotransferase (AST), alanine aminotransferase (ALT), γ -glutamyltransferase (γ -GTP)), kidney function test (blood urea nitrogen (BUN), creatinine) and biochemical analysis (total cholesterol, triglyceride, high-density lipoprotein (HDL), high-sensitivity C reactive protein (hs-CRP) and glycosylated haemoglobin (HbA1C)]. The low-density lipoprotein cholesterol (LDL) level was calculated using the Friedewald formula.⁴³

Health monitoring using national health data

All residents of Taean, including those in this study cohort, have been monitored for morbidity, mortality and cancer

incidence⁴⁴ using data provided by the National Health Information Database (NHID) and Korea National Cancer Incidence Database (KNCID).

The NHID⁴⁵ formed by the National Health Insurance Service is a public database on healthcare utilisation, health screening, sociodemographic variables and mortality for the whole population of South Korea, where the information of mortality was obtained from the Korean Statistical Information Service.²⁹ The KNCID⁴⁶ based on the nationwide, hospital-based cancer registry has been provided to the public, via the National Cancer Center.⁴⁷

Characteristics of study participants

Of the 9585 adults who participated in the HEROS study, 2052 resided in the high exposure area (47.8% of all residents in the areas) and 7533 resided in the low exposure area (12.8% of all residents in the areas). The demographic characteristics of adults aged ≥ 18 years old at the time of enrolment are provided in table 2. The distributions of age and gender did not differ significantly between residents of high and low exposure areas. Compared with the low exposure area, participants in the high exposure area were more likely to have a fishery-related occupation (58.1% vs 74.9%) and a lower socioeconomic status (education and household income), lower rate of smoking and alcohol intake, higher participation rate in clean-up work (87.3% vs 97.0%) and longer duration of clean-up work (median: 19 vs 122 days). The higher non-response rate (unknown category) in the variables of occupation, education, household income and so on from participants residing in the low exposure area might be due, at least in part, to a lower level of willingness to participate in this study and may indicate a possible volunteer bias between areas.

A total of 1 587 children (<13 years, kindergarten and elementary school students) and 629 adolescents (13–18

Table 2 General characteristics of the study subjects among adults (≥ 18 years) of Health Effect Research on Hebei Spirit Oil Spill study, Korea

	All	High exposure area N (%)	Low exposure area N (%)	P value
All	9585 (100.0)	2052 (21.4)	7533 (78.6)	<0.001
Years of first enrolment				
2009 (first survey)	9246 (96.5)	1741 (84.8)	7505 (99.6)	<0.001
2010 (second survey)	130 (1.4)	116 (5.7)	14 (0.2)	
2012 (third survey)	147 (1.5)	137 (6.7)	10 (0.1)	
2014 (fourth survey)	5 (0.1)	5 (0.2)	0 (0.0)	
2016 (fifth survey)	57 (0.6)	53 (2.6)	4 (0.1)	
Age at the oil spill accident (years, mean (SD))	59.5 (12.4)	59.4 (11.1)	59.5 (12.7)	0.541
Gender				
Male	3989 (41.6)	826 (42.0)	3163 (42.0)	0.160
Female	5596 (58.4)	1226 (58.0)	4370 (58.0)	
Occupation				
Fishing	5942 (62.0)	1563 (76.2)	4379 (58.1)	<0.001
Agriculture	1057 (11.0)	182 (8.9)	875 (11.6)	
Other	1113 (11.6)	199 (9.7)	914 (12.1)	
Unknown	1473 (15.4)	108 (5.3)	1365 (18.1)	
Household income (US\$/month)*				
≤ 890	5376 (56.1)	1449 (70.6)	3927 (52.1)	<0.001
891–1780	2288 (23.9)	390 (19.0)	1898 (25.2)	
≥ 1781	709 (7.4)	146 (7.1)	563 (7.5)	
Unknown	1212 (12.6)	67 (3.3)	1145 (15.2)	
Education level (years)				
<6	2309 (24.1)	575 (28.0)	1734 (23.0)	<0.001
6–11	5370 (56.0)	1232 (60.0)	4138 (54.9)	
≥ 12	607 (6.3)	90 (4.4)	517 (6.9)	
Unknown	1299 (13.6)	155 (7.6)	1144 (15.2)	
Smoking				
Non-smokers	6178 (64.5)	1541 (75.1)	4637 (61.6)	<0.001
Ex-smokers	991 (10.3)	199 (9.7)	792 (10.5)	
Current smokers	1273 (13.3)	265 (12.9)	1008 (13.4)	
Unknown	1143 (11.9)	47 (2.3)	1096 (14.5)	
Secondhand smoke exposure				
No	6350 (66.3)	1603 (78.1)	4747 (63.0)	<0.001
Yes	2086 (21.8)	402 (19.6)	1684 (22.4)	
Unknown	1149 (12.0)	47 (2.3)	1102 (14.6)	
Alcohol drinking				
No	5389 (56.2)	1359 (66.2)	4030 (53.5)	<0.001
Yes	3065 (32.0)	655 (31.9)	2410 (32.0)	
Unknown	1131 (11.8)	38 (1.9)	1093 (14.5)	
Clean-up work				
No	1015 (10.6)	62 (3.0)	953 (12.7)	<0.001
Yes	8570 (89.4)	1990 (97.0)	6580 (87.3)	
Days of clean-up work (median (Q1–Q3))	34 (0–97)	122 (0–147.5)	19 (0–64.5)	<0.001

P value estimated using χ^2 test or t-test and Wilcoxon-test.
*Income was calculated at the exchange rate of 20 August 2018.

years, middle and high school students) participated in the survey (table 3). Compared with the low exposure area, children and adolescents in the high exposure area were more likely to have parents with a fishing-related

occupation and a low household income, to have been exposed to firsthand and secondhand smoke, to have consumed alcohol and to have a higher rate of participation in clean-up work at the time of the oil spill.

Table 3 General characteristics of the study subjects among children (elementary school students) and adolescents (middle and high school students) of Health Effect Research on Hebei Spirit Oil Spill study, Korea

	Children				Adolescents				P value
	Total N (%)	All N (%)	High exposure school		All N (%)	High exposure school		Low exposure school N (%)	
			N (%)	N (%)		N (%)	N (%)		
All	2216 (100)	1587 (100)	315 (19.9)	1272 (80.1)	629 (100)	316 (49.8)	313 (50.2)	0.611	
Years of first enrolment									
2009 (first survey)	1172 (52.9)	705 (44.4)	210 (66.7)	495 (38.9)	467 (74.2)	310 (98.1)	157 (50.2)	<0.001	
2011 (second survey)	280 (12.6)	254 (16.0)	28 (8.9)	226 (17.8)	26 (4.1)	4 (1.3)	22 (7.0)		
2013 (third survey)	292 (13.2)	238 (15.0)	22 (7.0)	216 (17.0)	54 (8.6)	1 (0.3)	53 (16.9)		
2015 (fourth survey)	278 (12.6)	239 (15.1)	35 (11.1)	204 (16.0)	39 (6.2)	0 (0.0)	39 (12.5)		
2017 (fifth survey)	194 (8.8)	151 (9.5)	20 (6.3)	131 (10.3)	43 (6.8)	1 (0.3)	42 (13.4)		
Age at enrolment (years, mean (min, max))	10.2 (2,18)	8.4 (2,13)	8.8 (6,13)	8.3 (2,13)	14.6 (11,18)	15.5 (11,18)	13.7 (12,17)	<0.001	
Age at the oil spill (years, mean (SD))	6.6 (4,4)	4.6 (3,1)	6.0 (3,1)	4.3 (3,0)	11.3 (3,3)	13.5 (1,9)	9.1 (3,0)	<0.001	
Gender									
Male	1214 (54.8)	828 (52.2)	146 (46.3)	682 (53.6)	386 (61.4)	228 (72.2)	158 (50.5)	<0.001	
Female	1002 (45.2)	759 (47.8)	169 (53.7)	590 (46.4)	243 (38.6)	88 (27.8)	155 (49.5)		
Parents/guardian's occupation									
Fishing	379 (17.1)	249 (15.7)	71 (22.5)	178 (14.0)	130 (20.7)	81 (25.6)	49 (15.7)	<0.001	
Agriculture	321 (14.5)	186 (11.7)	63 (20.0)	123 (9.7)	135 (21.5)	76 (24.1)	59 (18.8)		
Service and office work	676 (30.5)	465 (29.3)	64 (20.3)	401 (31.5)	211 (33.5)	107 (33.9)	104 (33.2)		
Other	728 (32.9)	593 (37.4)	89 (28.3)	504 (39.6)	135 (21.5)	45 (14.2)	90 (28.8)		
Unknown	112 (5.1)	94 (5.9)	28 (8.9)	66 (5.2)	18 (2.8)	7 (2.2)	11 (3.5)		
Household income (US\$/month)*									
≤890	303 (13.7)	198 (12.5)	58 (18.4)	140 (11.0)	105 (16.7)	64 (20.3)	41 (13.1)	<0.001	
881–1780	617 (27.8)	415 (26.2)	99 (31.4)	316 (24.8)	202 (32.1)	109 (34.5)	93 (29.7)		
1781–2672	458 (20.7)	320 (20.2)	57 (18.1)	263 (20.7)	138 (22.0)	71 (22.5)	67 (21.4)		
≥2673	669 (30.2)	522 (32.9)	58 (18.4)	464 (36.5)	147 (23.3)	49 (15.5)	98 (31.3)		
Unknown	169 (7.6)	132 (8.3)	43 (13.7)	89 (7.0)	37 (5.9)	23 (7.3)	14 (4.5)		
Smoking									
Non-smoking	1987 (89.7)	1487 (93.7)	280 (88.9)	1207 (94.9)	500 (79.5)	230 (72.8)	270 (86.31)	<0.001	
Smoking	95 (4.3)	4 (0.3)	3 (1.0)	1 (0.1)	91 (14.5)	69 (21.8)	22 (7.0)		
Unknown	134 (6.1)	96 (6.0)	32 (10.2)	64 (5.0)	38 (6.0)	17 (5.4)	21 (6.7)		

Continued

Table 3 Continued

	Children				Adolescents				P value
	Total N (%)	All		Low exposure school		All N (%)	High exposure school		
		N (%)	N (%)	N (%)	N (%)		N (%)	N (%)	
Secondhand smoke exposure									
No	866 (39.1)	732 (46.1)	127 (40.3)	605 (47.6)	134 (21.3)	53 (16.8)	81 (25.9)	0.003	0.007
Yes	1257 (56.7)	771 (48.6)	161 (51.1)	610 (48.0)	486 (77.3)	256 (81.0)	230 (73.5)		
Unknown	93 (4.2)	84 (5.3)	27 (8.6)	57 (4.4)	9 (1.4)	7 (2.2)	2 (0.6)		
Alcohol drinking									
No	1787 (80.6)	1449 (91.3)	276 (87.6)	1173 (92.2)	338 (53.7)	132 (41.8)	206 (65.8)	0.012	<0.001
Yes	398 (18.0)	115 (7.2)	35 (11.1)	80 (6.3)	283 (45.0)	177 (56.0)	106 (33.9)		
Unknown	31 (1.4)	23 (1.5)	4 (1.3)	19 (1.5)	8 (1.3)	7 (2.2)	1 (0.3)		
Clean-up work									
No	1398 (63.1)	1104 (69.6)	213 (67.6)	891 (70.0)	294 (46.7)	108 (34.2)	186 (59.4)	<0.001	<0.001
Yes	401 (18.1)	147 (9.3)	59 (18.7)	88 (6.9)	54 (40.4)	200 (63.3)	54 (17.3)		
Unknown	417 (18.8)	336 (21.2)	43 (13.7)	293 (23.0)	81 (12.9)	8 (2.5)	73 (23.3)		

P value estimated using χ^2 test or t-test to compare the high and low exposure schools.

*Income was calculated at the exchange rate of 20 August, 2018.

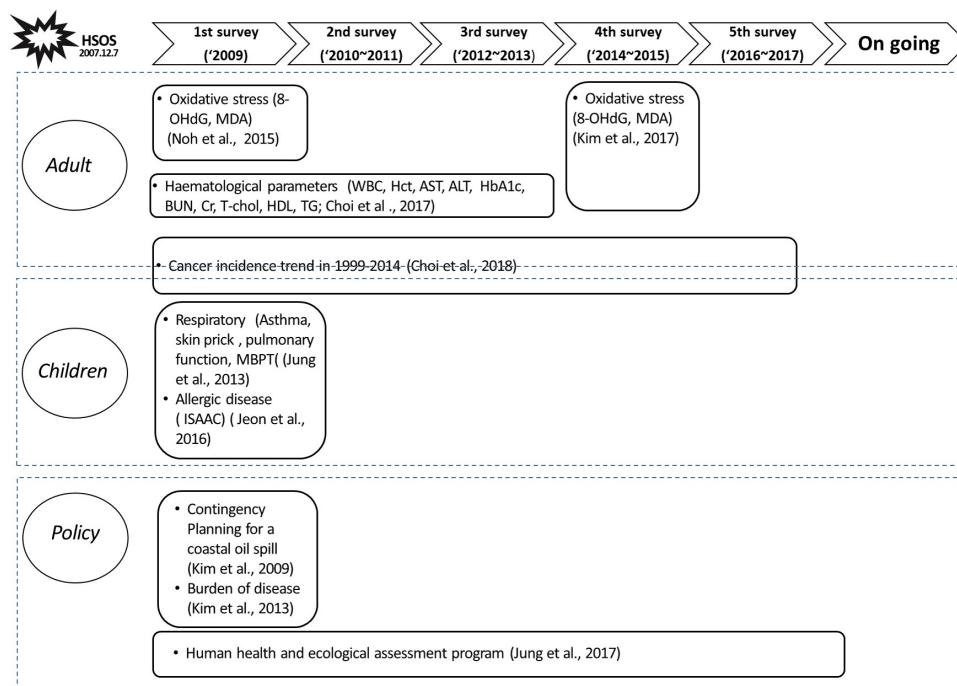


Figure 3 Publication summary to date of the Health Effect Research on Hebei Spirit Oil Spill study, Korea. 8-OHdG, 8-hydroxy-2-deoxyguanosine; ALT, alanine aminotransferase; AST, aspartate aminotransferase; BUN, blood urea nitrogen; Cr, creatinine; HbA1c, glycosylated haemoglobin; Hct, Hematocrit; HDL, high-density lipoprotein; ISAAC, International Study of Asthma and Allergies in Childhood questionnaire; MBPT, methacholine bronchial provocative test; MDA, malondialdehyde; T-cholesterol, total cholesterol; TG, triglyceride; WBC, white blood cell.

The 85 pregnant women enrolled at the time of the oil spill accident had a mean age of 30 years and 53% were educated for ≥ 13 years. Their offspring had a mean birth weight of 3.3 kg, and 62.3% were boys (data not shown).

Patient and public involvement

Participants and residents were not involved in the development of the study design, research questions or outcome measures. However, all participants received the results of their examinations.

FINDINGS TO DATE

The updated publication summary of the HEROS study is illustrated in figure 3. Exposure to spilled oil has been shown to correlate with respiratory symptoms⁴⁸ and allergic disease⁴⁸ in children and with levels of oxidative damage,^{19 49} hematologic parameters,⁵⁰ eating habits⁵¹ and cancer incidence⁴⁴ in adults in Taean. Additionally, the burden of disease (BOD)⁵² has been measured and a response contingency planning for oil spills⁵³ was provided.

One cross-sectional study⁴¹ showed that children who lived near the contaminated coastline had significantly higher rates of airway hyperresponsiveness and asthma, a lower forced expiratory volume in one second, and a higher rate of wheezing at 1.5 years after the HSOS accident, compared with those who lived further from the coastline. Another study found that children's symptoms of allergic rhinitis during the last 12 months were associated with the vicinity of residence to the oil spill area (OR:

1.88, $p=0.025$) and participation in the clean-up activities (OR: 1.93, $p<0.05$).⁴⁸

The levels of oxidative stress biomarkers (MDA, 8-OHdG) increased according to the total duration of clean-up work and persisted for 1.5 years after the oil spill accident (MDA: p -trend <0.0001 ; 8-OHdG: p -trend <0.0001).¹⁹ Similarly, the levels of 1-OHP and 2-NAPH increased proportionally with the total duration of clean-up work after adjusting for covariates (1-OHP; p -trend=0.007, 2-NAPH; p -trend=0.05). The level of 1-OHP exhibited significantly positive associations with the urinary levels of both MDA ($p=0.04$) and 8-OHdG ($p=0.0009$) after covariate adjustment. However, similar associations were not observed with 2-NAPH levels. Another cross-sectional study⁴⁹ showed that even 6 years after the spill, residents who lived near the contaminated coast had significantly higher levels of 8-OHdG (p -trend=0.0235), compared with those who lived further away. In addition, the duration of clean-up activities was found to associate significantly with both the urinary 8-OHdG (p -trend=0.0083) and MDA levels (p -trend=0.0370).

One previous study investigated the relationship between oil exposure and haematological parameters among 701 residents in the high exposure area who participated in both the 2009 and 2012 surveys.⁵⁰ In that study, the white blood cell count and levels of hematocrit, AST, ALT, glucose and HbA1C were significantly increased, whereas the levels of BUN, creatinine, HDL and triglycerides were significantly decreased.

Exposure to oil also affected the dietary habits of adults. A study of focus group interviews on 5 groups of 46 women who lived near the oil spill area and prepared meals at home was conducted 1.5 years after the accident and found that most participants reported frequent physical symptoms such as skin problems, vomiting, visual weakness and dizziness after clean-up work.⁵¹ Participants also reported eating more vegetables and fewer servings of meats or fish due employment losses and a lack of household income.

A study of the cancer incidence trends in Taean County, which was based on Korean Cancer registry data, showed that from 2007 to 2009, the annual incidence rate of prostate cancer appeared to increase at a more rapid rate than the rates reported nationwide and in three other coastal areas of Korea (Taean: 39.3%, 95% CI –25.9 to 161.8; nationwide: 13.5%, 95% CI 11.7 to 15.4; three coastal areas: 15.6%, 95% CI 11.9 to 19.5).⁴⁴

The BOD due to oil spills was determined in residents of Taean using disability-adjusted life years (DALYs).⁵² In 2008, the years lived with disability (YLD) due to the oil spill were estimated to be 14 724 DALYs (males: 7 425 DALYs; females: 7 299 DALYs). The YDL of mental disease (PTSD and depression) were higher among men than among women. In contrast, the YLD of asthma and allergic disease (rhinitis, dermatitis and conjunctivitis) were higher among women than among men. Closer proximity to the oil spill site was associated with an increased BOD.

The findings of the HEROS study suggest the need to establish an emergency response system to protect environmental and public health⁵³ and increase collaborations between various sectors in efforts to protect human health, as well as the health of environments and ecosystems after an oil spill.⁵⁴

Strengths and limitations

The HEROS study is a prospective cohort study of a general population exposed to an oil spill that includes not only adults but also children and pregnant women. It is also a panel study that obtained repeated measures of exposure and health outcomes from the same participants. One advantage of a panel study is the reduction in interpersonal variation, which leads to an increase in statistical power. Additionally, a panel study can examine changes over time in exposure biomarkers and health indicators.

The HEROS study has created a bank of blood and urine samples collected repeatedly from participants since 2009. These samples can be used in various studies to evaluate oil exposure and health effects over time since the accident.

However, the HEROS study has some limitations. First, the actual ambient exposure at the time of the HSOS was not measured, and therefore a modelling study was performed to estimate the inhalation exposure.⁴⁰ Second, this study did not include coast guard personnel, military personnel and medical staff who were assumed to

have been highly exposed due to extensive clean-up work participation. Third, the exposure assessment did not consider the use of oil dispersants and air compressors. However, most of the clean-up was performed manually using absorptive materials, while air compressors and oil dispersants were applied only by professional workers or the Korean Coast Guard. Therefore, we can assume that HEROS participants were not involved in the use of air compressors or oil dispersants.

Collaboration

Data generated by the HEROS will be shared with researchers and investigators who are interested in related topics. Researchers who wish to work with these data should contact the team at the TEHC (oilspill2007@gmail.com) and send a concept sheet for the analyses aim to perform and the variables that would be required. The author (M-SP) can be contacted for more information (oilspill2007@gmail.com).

PERSPECTIVES AND CONCLUSION

Oil spills are serious environmental disasters related to the extensive global use of fossil fuels. The enforcement of double-hull oil tankers has significantly reduced the frequency and scale of oil spills worldwide. However, the human health effects of smaller-scale oil spills can also be extensive and long-lasting. Despite the need to trace the long-term health effects of oil spills, such work has only been conducted for short periods of time, and only two such previous studies have been published.^{17 18} In those studies, the health effects of oil spills were studied only in limited areas, and a delay between the oil spill and the beginning of the study was frequently present. Thus, a long-term prospective cohort study such as the HEROS can contribute to the appropriate management of future oil spills. In the 10 years since the HSOS, the HEROS has produced important data that can be used globally to increase scientific knowledge and prevent or reduce the adverse health effects of future oil spills on community residents.

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Contributors JI-H, H-KC and MH conceived, designed and executed this study. MSP and K-HC obtained, managed and analysed the data and wrote the paper. W-CJ, SRN and S-HL executed the study. MH reviewed final manuscript and provided critical and constructive comments. All authors read and approved the final version of the manuscript.

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Ethics approval The study protocol was approved by the Institutional Review Board (IRB) of Dankook University Hospital, Cheonan, Republic of Korea. Participants provided their written consent to participate in this study. We obtained written consent from adult participants, and the parents or guardians on behalf of the adolescents and children enrolled in this study (IRB no. 2013-09-009, 2014-06-013, 2015-07-020, 2015-12-012 and 2017-03-032).

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Data availability statement The HEROS data can be accessed from the Taeon Environmental Health Center. Applications to use the HEROS data will be reviewed by the committee of research support and once approved, raw data will be provided to the applicant. Although the data are allowed only for Korean researchers at the moment, but it would be possible for researchers outside the country to gain access to the data by conducting a joint study with Taeon Environmental Health Center.

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