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Review

Crude Oil Spills and Respiratory Health of Clean-Up Workers: A Systematic Review of Literature

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Abstract: Background: We systematically reviewed the literature's existing knowledge on crude oil spills and the respiratory health (RH) outcomes of clean-up workers. Methods: We searched PubMed, Google Scholar, SCOPUS, Web of Science, and Science Direct databases to systematically review studies of crude oil spills and RH outcomes of clean-up workers published from 1 January 2001 to 30 June 2022. We excluded in vitro, animal, and household studies. Results: We identified 20 articles assessing the relationship between crude oil spills and RH outcomes of clean-up workers. Most studies were prospective and analytical, and fewer studies were cross-sectional studies. Most articles showed short- and long-term RH effects, with two articles refuting the adverse long-term RH effects and five articles showing no significant differences. Less than 50% of the articles assessed RH using spirometry. Studies on some independent oil spills (Hebei Spirit) were limited. Conclusion: There is a high level of exposure to crude oil spills by clean-up workers, which is associated with adverse RH effects. Integrated efforts are needed to curb the menace of oil spills, thereby reducing the adverse RH effects among this vulnerable population.

Keywords: crude oil spills; oil pollution; clean-up workers; air pollution; RH effects

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1. Introduction

Crude oil is a very important raw material that can be a lifeline of a nation's economy, security, and political stability. The discovery of crude oil and its exploration and exploitation have both positively and negatively impacted nations across the world [1]. Oil exploration can be associated with the heavy price of environmental degradation and biodiversity loss, as well as the destruction of human lives and properties [2,3].

Crude oil is a composite substance which is made of diverse elements and compounds, especially hydrocarbons. The hydrocarbons mainly found in crude oil are classified into three types: alkanes (paraffins), cycloalkanes (naphthenes), and arenes (aromatics) [4,5]. These compounds have varying molecular weights. Crude oil exists in two clear-cut physical states, namely light and heavy crude. At room temperature, light crude, which is of a lower density, viscosity, and molecular-weight hydrocarbon composition, flows easily, while heavy crude, which has a high density, viscosity, and molecular-weight hydrocarbon composition at room temperature, has its free flow hindered [6]. During a spill, there is a release of compounds in the environment, ranging from volatile organic compounds (VOCs) to heavy metals [7]. These VOCs include benzene, toluene, ethylbenzene, xylene (BTEX), and polycyclic aromatic hydrocarbons (PAHs) [8,9].

Oil spills occur in varying degrees and are influenced by several factors. While some spills may occur naturally, others are manmade. Naturally occurring oil spills may be caused by crude oil seeping from underneath the earth's surface, volcanic eruptions, natural fires, and thermal geological reactions [10]. Anthropogenic or manmade causes of oil spills can be due to the following: artisanal refining; vandalism of oil pipelines, sabotage, poor maintenance of crude oil infrastructures; and exploration, extraction and transportation processes, and accidents (stranding, hull damage, collision, equipment failure, fire/explosion, etc.) [2,11,12]. Some of the significant spills that have taken place globally include the following: the Exxon Valdez, Deepwater Horizon (DWH), Hebei Spirit, Torrey Canyon Tanker, Santa Barbara, Prestige, and the Niger Delta Oil Spills [13–16].

The environment plays a major role in the physical and chemical state of the oil spilled. The oil spilt undergoes complex reactions involving physical, chemical, and biological processes. These processes are termed 'weathering', which results in the natural cleaning (decaying of spilt oil) of the environment, thereby reducing the toxic and harmful effects of the spilled oil [17,18]. The major physical processes include spreading, evaporation and aerosolization, dispersion as small droplets, solution, adsorption, and sinking of sediment particles [19]. The weathering process can also take place via chemical oxidation being influenced by light and biological actions involving the activities of different species of bacteria and fungi which degrade the hydrocarbon [20,21]. Evaporation and aerosolization of crude oil reduce its concentration in the liquid phase and increase its toxicity in the atmosphere, thereby increasing its debilitating effects on human respiratory health (RH) [22,23].

Exposure to an oil spill disaster can either be direct (primary) or indirect (secondary). Direct exposure may be via (1) the respiratory tract as aerosols or particulate pollutants from oil spills are inhaled; (2) the gastrointestinal tract following ingestion; or (3) dermal contact with oil, tar, or dispersant [4]. Secondary or indirect exposure occurs when an individual is exposed to an impacted entity or ecosystem but not exposed directly to the event. These secondary exposures include disruption of daily routines and activities, loss of livelihood, relocation, anxiety, etc., and these exposures are a result of the destruction of lands and marine ecosystems by the spill [24]. These pollutants can either exert their effects on the organs at the point of entry into the body or enter systemic circulation. The degree of absorption of these toxicants is dependent on the particle size, aqueous solubility, and lipophilic nature. According to [10], these compounds can be biotransformed in the presence of enzymes such as Cytochrome P450 in the body into their metabolites. Phase I metabolism involves the conversion of the compound structure, thereby increasing its polarity, which makes it more electrophilic and increases its reactivity such as oxidation; meanwhile, Phase II metabolism, such as conjugation, entails adding polar groups to the compound, increasing its bulkiness and aqueous solubility. These metabolites are then excreted either via faeces or urine [10].

The World Health Organization (WHO) reports about seven million deaths yearly from all around the world due to polluted air, with the majority of the global population inhaling air with substances that exceed WHO limits [25]. Ambient air pollution was estimated to have caused over 4 million deaths globally in 2016, and these deaths were mainly a result of exposure to the fine particulate matter ($PM_{2.5}$) which causes respiratory diseases, cardiovascular diseases, and cancers [26]. Outdoor air pollution is a serious environmental health challenge that affects humans, with the vulnerable population being more susceptible [27]. For 2016, it was estimated that about 60% of premature deaths linked to outdoor air pollution were due to stroke and ischaemic heart disease, approximately 20% were a result of acute lower respiratory conditions and chronic obstructive pulmonary disease (COPD), and 6% were because of lung cancer [27]. Crude oil spills play an important role in negatively impacting not only the land and water where the spill occurs, but also the air (atmosphere) where the spill occurs [28]. It can also explode, thereby leading to the release of toxic substances into the environment, which is detrimental to health. These compounds include sulphur dioxide (SO_2), nitrogen dioxide

(NO_2), $PM_{2.5}$, $PM_{0.1}$, and VOCs, to mention but a few. These pollutants disrupt both the ambient air and the indoor air quality [29].

Respiratory disease has been found globally to be one of the leading causes of illness and death [30]. It accounts for more than 10% of all disability-adjusted life years (DALYs), which is a metric that gives an assessment of the amount of active and fruitful life lost due to a condition [31]. They include COPD, the third-leading cause of mortality worldwide, accounting for about 3 million mortalities; asthma, with over 300 million people affected; lower respiratory tract infections, resulting in about 4 million deaths; as well as tuberculosis (1.4 million deaths) and cancers (1.6 million deaths) [31]. For example, inhalation of toxicants such as the VOCs, including benzene, toluene, and formaldehyde, released from crude oil can irritate and inflame the respiratory system through the production of reactive oxygen species (ROS) and contribute to respiratory symptoms such as wheezing, coughing, and shortness of breath. In addition, PAHs in crude oil, which are known carcinogens, can cause respiratory damage when inhaled by inducing inflammatory responses and interfering with cellular signaling pathways through the generation of ROS, leading to toxicological effects including acute respiratory infections, COPD, and the development of lung cancer [32,33].

The human respiratory system is made up of structures that provide defense mechanisms that can trap foreign particles and toxicants [34]. These defense mechanisms may be weakened due to increased stressors in clean-up workers and oil spill responders, thus making them more susceptible to respiratory health problems [35]. Vulnerability means susceptibility; in health care, it refers to those at risk for health conditions. According to [36], vulnerable populations may be defined as people with a greater propensity of developing disease conditions by virtue of their disadvantaged socio-cultural status, restricted access to economic resources, or their individual susceptibility such as gender and age. In this study, clean-up workers, by virtue of their increased exposure to oil after a spill, are categorized as a vulnerable population.

There seems to be a paucity of reviews regarding the RH outcomes of crude oil on clean-up workers globally. Hence, this review aims to systematically assess available data on the RH effects associated with crude oil spills on clean-up workers. The findings of this review will give a robust conclusion on this topic, help in policymaking, prioritize measures in controlling oil spills with the safety of the clean-up workers put in serious consideration and prompt management of the respiratory diseases associated with this exposure. This will ensure safer and cleaner air, which will translate to better RH for oil spill responders.

2. Methods

The Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines formed the basis on which this systematic review was developed [37]. Studies that formed part of this review were epidemiological research that described the relationship between crude oil spills and the RH of clean-up workers globally. The scope of the study is defined by the following research question: "in clean-up workers, is exposure to oil spills and its constituents associated with adverse changes in their RH?"

2.1. Search Strategy

A vast search for literature was performed between July 2021 and October 2022 on PubMed, Science Direct, SCOPUS, Web of Science, and Google Scholar research databases to capture the necessary literature. Several keywords were used to collate relevant literature from the selected databases. MeSH terms were used as follows: {"Crude oil spills" OR "Oil spills" OR, "Oil pollution" OR "Oil spillage"} AND {"Respiratory" OR "Lung function" OR "Pulmonary function" OR "Spirometry"} AND {"Clean-up workers" OR "Response workers"}.

2.2. Study Selection

The inclusion and exclusion criteria stated below were used in selecting studies for this review.

2.3. Inclusion Criteria and Exclusion Criteria

The study selection criteria regarding the RH outcomes were the study population (clean-up workers or response workers); exposure of interest (crude oil spill); the outcome of interest (adverse changes in respiratory health); and study design (epidemiologic studies using cross-sectional, panel studies, case–control, cohort designs, longitudinal studies). Screenings of the titles of the studies, their abstracts, and their full texts were performed to select studies for this systematic review. A study was considered for inclusion if it was written in the English language and published between 2001 and 2022; if it was an epidemiological study; and if it described the relationship between oil spills and RH effects as it pertains to clean-up workers. Studies with duplicates studies not written in the English language and that exceeded the scope of the review were excluded. Reviews were also excluded.

2.4. Quality of Evidence

Quality assessment criteria for observational studies which are based on the Newcastle–Ottawa Scale (NOS) was used in assessing the quality of the studies in this systematic review [38]. The traditional NOS makes use of an eight-item rating system to assess the method of selection of participants, comparability among study groups, and the exposure/outcome assessment. However, the quality assessment criteria for observational studies have two additional criteria in the selection of participants, including precision of exposure, dose ascertainment, and ascertainment of exposure performed prospectively or retrospectively [38]. The quality was then considered based on the risk of bias (ROB), that is, either low, medium, or high ROB. Comparability was assessed by controlling for potential confounders in terms of study design, analysis, and the type of health effects under evaluation.

2.5. Data Extraction and Data Synthesis

Screenings of all titles, abstracts, and full texts were performed in accordance with the inclusion and exclusion criteria. Relevant data from included studies were retrieved using the data extraction form. The data extracted were information on authors, year of publication, country of study, study period, study setting, study design, study population, sample size, exposure of interest, method of assessing the exposure/outcome variables, respiratory health effect (with the effect estimate and the associated 95% CI, where available), and confounding variables.

A narrative synthesis of the included studies was performed and the tables summarizing the findings of the included studies are shown in Tables 1 and 2. A PRISMA flowchart for eligible study selection is presented in Figure 1. A meta-analysis was not performed due to the diversity in the methodologies applied in the assessment of exposures and outcome variables.

Table 1. Summary of crude oil spills captured in this study.

S/N	Name of Spills	Study Location	Year of Spill	Quantity Spilled	Reference
1.	Tasman Spirit Oil Spill	Coastal areas of Karachi, Pakistan	2003	35,298 KL (30,000 tons)	[39–41]
2.	Deepwater Horizon Oil Spill	Gulf of Mexico	2010	About 757,082 KL (200 million gallons or 4,761,905 barrels or 649,645 metric tons)	[8,42–51].
3.	Hebei Spirit Oil Spill	Taean area, Korea	2007	12,942.6 KL (an estimated 11,000 tons)	[52,53].
4.	Prestige Oil Spill	Asturia and Cantabria, Spain	2002	77,123.8 KL (67,000 tons) of bunkered oil	[54–57].

Table 2. Summary of Respiratory Health Effects.

S/N	Reference; Study Location and Study Period	Study Design, Study Population, Sample size	Oil Spill	Methods of Assessing Respiratory Effects	Study Findings	Adjustment for Confounding Factors
1.	[39]; Karachi, Pakistan; August 2003–2004	[a] CS with a 1-year follow-up study; Clean-up workers (n = 20 males) vs. matched controls (clerical staff, shopkeepers, and salesmen) (n = 31 males)	Tasman Spirit oil	Spirometry; Detailed interview, Questionnaire	A remarkable decrease in FVC, FEV1, (FEF25–75%), and MVV in those exposed to polluted air in comparison to matched controls.	Age, height, body mass, socio-economic status (SES), cigarette smokers, respondents with industrial exposure to smoke or dust
2.	[40]; Coastal areas of Karachi, Pakistan; July 2003–December 2004	[a] CC; Clean-up workers; (healthy men, n = 50) vs. controls (clerical staff, shopkeepers, and salesmen) (n = 50)	Tasman Spirit oil	Standardized Questionnaire, Detailed interview	Greater prevalence of cough, rhinorrhoea, sore throat, malaise, dyspnoea, chest tightness, phlegm, and wheeze, which were 40%, 36%, 30%, 18%, 14%, 10% and 6%, respectively, compared to controls. The odds of sore throat; cough and runny nose ((OR, 95% CI): 6.09, 2.0–22.8; $p < 0.006$ *); (9.60, 2.61–35.22; $p < 0.0002$ *); and (14.0,3.0–62.0; $p < 0.0001$ *) were markedly higher among the clean-up workers than the controls.	Age, sex, SES, respondents addicted to drugs, cigarette smokers, exposed to smoke and dust from any industry, and working at petrol pumps and gas stations
3.	[41]; Coastal areas of Karachi, Pakistan; July 2003–December 2004	Comparative study; Clean-up workers; Healthy, non-smoking male workers, n = 31 vs. clerical staff, shopkeepers and salesmen, n = 31	Tasman oil	Standardized Questionnaire; Spirometry	Being exposed to the spill had a decrease in FVC, FEV1, FEF25–75%, and MVV that is statistically significant ($p = 0.001$ *; 0.001 *; 0.002 *; and 0.001 *). Exposure to these pollutants for less than 8 days had a significant difference in only FVC ($p = 0.001$); for 8–15 days revealed a significant difference for FVC ($p = 0.05$); and for greater than 15 days, revealed a significant decrease in for FVC, FEV1, FEF25–75%, and MVV in the exposed group relative to their controls ($p = 0.001$ *; 0.001 *; 0.02 *; and 0.002 *).	Subjects that smoke, SES, occupational exposure history, Age, Height, Weight

4.	[49]; Gulf of Mexico; (20 April–17 December 2010	[a] PS, CS; DWH oil spill responder (US Coast Guard personnel); (n = 8700) and non-responders (n = 44,800)	DWH oil spill following oil rig explosion	Objective health data, Survey data	Increased PRs were statistically significant and this increased with exposure for all three symptoms: cough (PR = 1.6–1.8); wheeze (PR = 2.1–2.3); dyspnoea (PR = 1.8–2.3). Elevated risk for chronic respiratory diseases (RR = 1.3; 95% CI: 1.0 to 2.0), with asthma inclusive (RR = 2.0; 95% CI 1.0 to 3.2); increased RRs were also found for COPD (RR = 1.4; 95% CI: 0.97 to 1.90) 2.5 years after exposure.	-
5.	[51]; Gulf of Mexico; 1 October 2007–30 September 2015	Prospective analysis; Prospective follow-up; (US Coast Guard personnel) responders vs. non-responders; n = 45,190	DWH oil spill following oil rig explosion	Medical encounter data	Responder/non-responder: Weak elevated adjusted hazard ratios (aHRs) Responder comparisons: Stronger risks with exposure to crude oil. Exposure through inhaling the pollutants: Elevated risks for all sinusitis, unidentified long-term sinusitis, COPD and other related health conditions, and dyspnea and respiratory abnormalities [(aHR; 95% CI) (1.5; 1.1–2.1), (1.6; 1.1–2.2), (1.4; 1.0–2.1), (1.3; 1.0–1.7)]; elevated risk for diseases categorized as asthma and reactive airway diseases, including the specific condition, asthma, the symptom, dyspnoea, and the general categorization of long-term respiratory conditions [(aHR;95% CI): (1.2; 1.0–1.4), (1.4; 1.0–2.3), (1.5; 1.0–2.5), and (1.2; 1.0–1.4). Positive associations between exposure to both crude oil and dispersant and an increased risk for shortness of breath (HR = 2.0; 95% CI, 1.0–5.0).	Smokers
6.	[50]; Gulf of Mexico; January 2010 and November 2012	[a] CS; Clean-up workers; n = 247 subjects (exposed vs. non-exposed, 117 vs. 130)	DWH oil spill following oil rig explosion	Self-reported data on somatic symptoms	Some respiratory somatic symptoms include headache 77%, dyspnoea 71%, dermatitis, chronic cough 52%, chest pain 38%.	-
7.	[42]; Gulf of Mexico;	Follow-up study after 7-years exposure; Clean-up workers; exposed = 44, non-exposed = 44	DWH oil spill following oil rig explosion	Medical records and charts	After 7-years exposure (long-term exposure), chronic rhinosinusitis and reactive airway dysfunction syndrome developed.	-

8.	[8]; Gulf of Mexico; 20 April 2010–15 July 2010 vs. after 15 July 2010–30 September	[a] CS; United States Coast Guard personnel; (n = 4855)	DWH oil spill following oil rig explosion	Self-reported data; Questionnaire	Cough (19.4%); dyspneoa (6.0%); wheeze (4.0%) Adjusted analyses showed elevated PRs for cough (PR = 1.9), dyspnoea (PR = 2.6), wheeze (PR = 2.7) for any exposure to oil. A sub-analysis was performed comparing those responders who were exposed to oil alone, those exposed to a combination of oil and oil dispersant, and those who were not exposed. Exposure to oil alone had raised PRs for cough, dyspnoea, and wheeze [(PR;95% CI): (1.7; 1.4–2.0), dyspnoea (2.0; 1.2–3.0), and wheeze (2.0; 1.4–3.6). Greater PRs recorded with respect to cough during exposure to a combination of oil and oil dispersant (PR: 2.7; 95% CI: 2.3–3.2), dyspnoea (PR: 5.0; 95% CI: 3.3–7.0), wheeze (PR: 5.1; 95% CI: 3.2–8.0).	Duration of deployment
9.	[43]; Gulf of Mexico; May 2011–May 2013	[a] PC Case analysis; Clean-up workers; n = 4806	DWH oil spill following oil rig explosion	Spirometry; Questionnaire	Higher FEV1 (MD: 30 mL; 95% CI: −3, 64), and FVC (MD: 30 mL, 95% CI: −9, 69) values among those that smelled chemicals than unexposed workers. A significantly lower FEV1 (MD: −70 mL, 95% CI: −105, −30), FVC (MD: −60 mL, 95% CI: −97, −15) and FEV1/FVC (MD: −0.60%, 95% CI: −1.0, −0.2) among clean-up workers with exposure due to oily flora/fauna or dead animal recovery jobs compared to unexposed [FEV1 (MD: −50 mL, 95% CI: −80, −20); FVC (MD: −45 mL, 95% CI: −80, −9); FEV1/FVC ratio (MD: −0.4%, 95% CI: −0.80, −0.07)].	Maximum ordinal THC exposure levels, exposure to blazing oil/gas and dispersant; age in years, height, height-squared, body mass, male/female, origin, race; diabetes and pulmonary disease diagnosis before the spill; salary, education, employment, subjects with a history of oil company experience and clean-up operations; residing close to coastal regions, smokers and secondhand smoking (SHS) history
10.	[44]; Gulf of Mexico; May 2011–May 2013	[a] PC; Clean-up workers; n = 7780	DWH oil spill following oil rig explosion	Spirometry; Questionnaire	Some decrease in FEV1 (β: −70 mL, 95% CI: −130, −10) in decontamination workers compared to support workers. Exposed workers to flaming oil/gas had decrements in their pulmonary function with respect to the unexposed workers: FEV1 and FEV1/FVC [(β;95% CI): −180 mL; −320, −50) and (β: −2.0%; −3.5, −0.4), and a raised risk of having a FEV1/FVC in the minimum tertile (PR: 1.4, 95% CI: 1.0–2.0)	Age; male/female; race; educational attainment; employment; past medical history of lung disease and diabetes; and work-related exposure history, residential proximity, exposure to secondhand smoke

11.	[45]; Gulf of Mexico;	[a]PC; Clean-up workers; n = 6288 workers	DWH oil spill following oil rig explosion	Questionnaire; Spirometry	The lung function in general was not different by THC exposure levels among workers who partook in clean-up activities, who were highly exposed compared to the less exposed, hence no association was noticed between THC exposure and pulmonary function of workers that participated in clean-up operations 1 to 3 years after the spill	Age; gender; race; educational attainment; employment; past medical history of lung disease and diabetes; and work-related exposure history; residential proximity, exposure to secondhand smoke
12.	[48]; Gulf of Mexico; 15 May to 15 July 2010	[a]PC; Clean-up workers (exposed to burning and referent group); n = 2320 (n = 518 and n = 1798)	DWH oil spill following oil rig explosion	Spirometry; Questionnaire	Exposure–response trends showed significant associations between elevated total daily greatest $PM_{2.5}$ exposure with reduced FEV1 (*p*-trend = 0.04), FEV1/FVC (p-trend = 0.01). Compared with less-exposed workers, those with greater total exposures had decrements in FEV1 [−167.0 mL, 95% CI: −337.0, 4.0] and FEV1/FVC (−2.0, 95% CI: −4.0, 0.2). A significant observation was made between average daily greatest exposure and FEV1 (p-trend = 0.02) and significantly lower FEV1 (−228.0 mL, 95% CI: −431.0, −25.0) among the workers who never smoked in the high-exposure group, as well as a lower FVC among never-smokers with higher average and cumulative daily maximum exposures. A statistically significant trend for the association between cumulative daily maximum exposure and FEV1/FVC (p-trend = 0.01) accompanied by insignificantly lower FEV1/FVC in the high-exposure group (−3.0%, 95% CI: −6.0, 0.1) in the never-smokers subgroup	Sex, race, highest educational attainment; employment; cigarette smoking status; past medical history of lung disease and diabetes; and occupational exposure history, residential proximity to spill, exposure to secondhand smoke
13.	[46]; Gulf of Mexico; Between August 2014 and June 2016	[a] PC; OSRC; n = 1840 (Worker vs. Non-worker: 270 vs. 1570)	DWH oil spill following oil rig explosion	Questionnaire; Spirometry	A total of 4–6 years after exposure, clean-up responders with THC exposure 1.0–3.0 ppm and ≥3.0 ppm had higher FEV1 when compared to responders with ≤0.3 ppm (β: 110 mL, 95% CI: 20, 200), and (β: 120 mL, 95% CI: 5–230). Decrease in lung function was no longer evident after 4–6 years. Greatest exposures had the greatest improvement in their respiratory health.	Age; age[2]; height; height-squared; weight; female/male; Hispanic ethnicity; race; past medical history of diabetes or lung disease; educational level; occupation; previous oil company involvement; previous oil spill response history; smoking status

14.	[47]; Gulf of Mexico;	[a] PC; Clean-up workers; N = about 24,610 (19,020 workers; 5590 nonworkers)	DWH oil spill following oil rig explosion	Self-reported data using Questionnaire	Workers who participated in the clean-up activities had greater risks of developing asthma than non-workers (RR: 1.6, 95% CI: 1.0–2.0). Increased risk with exposure to higher THC levels (p < 0.0001 *). Risk of developing asthma was elevated with an elevated exposure to individual BTEX-H chemicals and the chemical mixture RR: 1.5; 95% CI: 1.4–1.6. For physician-diagnosed asthma, associations were less apparent.	Age; male/female; Hispanic ethnicity; race; past medical history of diabetes or lung disease; highest educational attainment; employment status; history of prior oil company experience; history of oil spill cleanup operations; smoking status
15.	[52]; Taean County, Korea; January 4 to February 19 2008	[a] CS Survey; Clean-up workers—Military personnel; n = 2624	Hebei Spirit oil	Structured self-assessment Questionnaire	Cough, sore throat, runny nose, dry mouth, sputum, with younger age group having fewer symptoms than the older age groups.	-
16.	[53]; Taean Area, Korea; December 13 to 20, 2007	[a] CS Survey; Residents, Volunteers and Clean-up workers; (n = 846)	Hebei Spirit oil	Questionnaire; Interviews	Respiratory symptoms (sore throat, cough, respiratory discomforts) OR: 1.5 (1.3–1.8).	Age, female/male, status, duration of clean-up activities, and hours worked per day
17.	[54]; Atlantic Coast/Cantabrian Coast, Spain; September 2004 and February 2005	[a] CS; Clean-up workers (Fishermen and women) exposed = 501; non-exposed= 177	Prestige oil	Questionnaire survey, Interviews; Spirometry	Risks for symptoms of lower respiratory tract diseases elevated (RD: 8.0 [95% CI: 1.0 to 15.0]), increased biomarkers of airway injury in the exposed. No remarkable difference in pulmonary function between the two categories.	Sex, smoking status
18.	[56]; Asturia and Cantabria, Spain; 29 November 2002 to 21 July 2003	Census survey; Clean-up workers-Sea men, volunteers, bird cleaners, paid workers (n = 799)	Prestige oil	Structured questionnaire; computer-assisted telephonic interviews	A statistically significant association between Prestige Spirit oil spill exposure and throat and respiratory health issues OR: 10.4 [95% CI 4.0–27.4] p < 0.001 *.	-
19.	[55]; Asturia and Cantabria, Spain; 2008	A follow-up study; Clean-up workers; n = 501 exposed vs. n = 177 unexposed	Prestige oil	Structured validated questionnaire; computer-assisted telephonic interviews	Higher prevalence of lower respiratory tract symptoms (e.g., wheeze, dyspnoea, cough, and sputum production) in the exposed (RR 1.4, 95% CI 1.0–2.0). With increase in the degree of exposure, there was a corresponding increased risk of chronic respiratory symptoms: RR: 1.7 (95% CI 0.9–3.1) and 3.3 (95% CI 1.8–6.0) for averagely and profoundly exposed, respectively, as against those that were symptomless.	Sex, age, smoking status
20.	[57]; Spain; November 2008–April 2009	A follow-up longitudinal study; Clean-up workers (Exposed vs. Unexposed Fishermen); (n = 160 vs. 60)	Prestige oil	Respiratory function testing (spirometry); Methacholine challenge test	Similar or better respiratory health statistics were observed in oil spill responders when compared to the non-exposed 6 years after the spill (FEV1/FVC and FEF25–75% were increased remarkably).	Smokers

[a] CS—Cross-sectional study; PS—Prospective study; CC- Case–control; * statistically significant $p < 0.05$.

PRISMA FLOWCHART

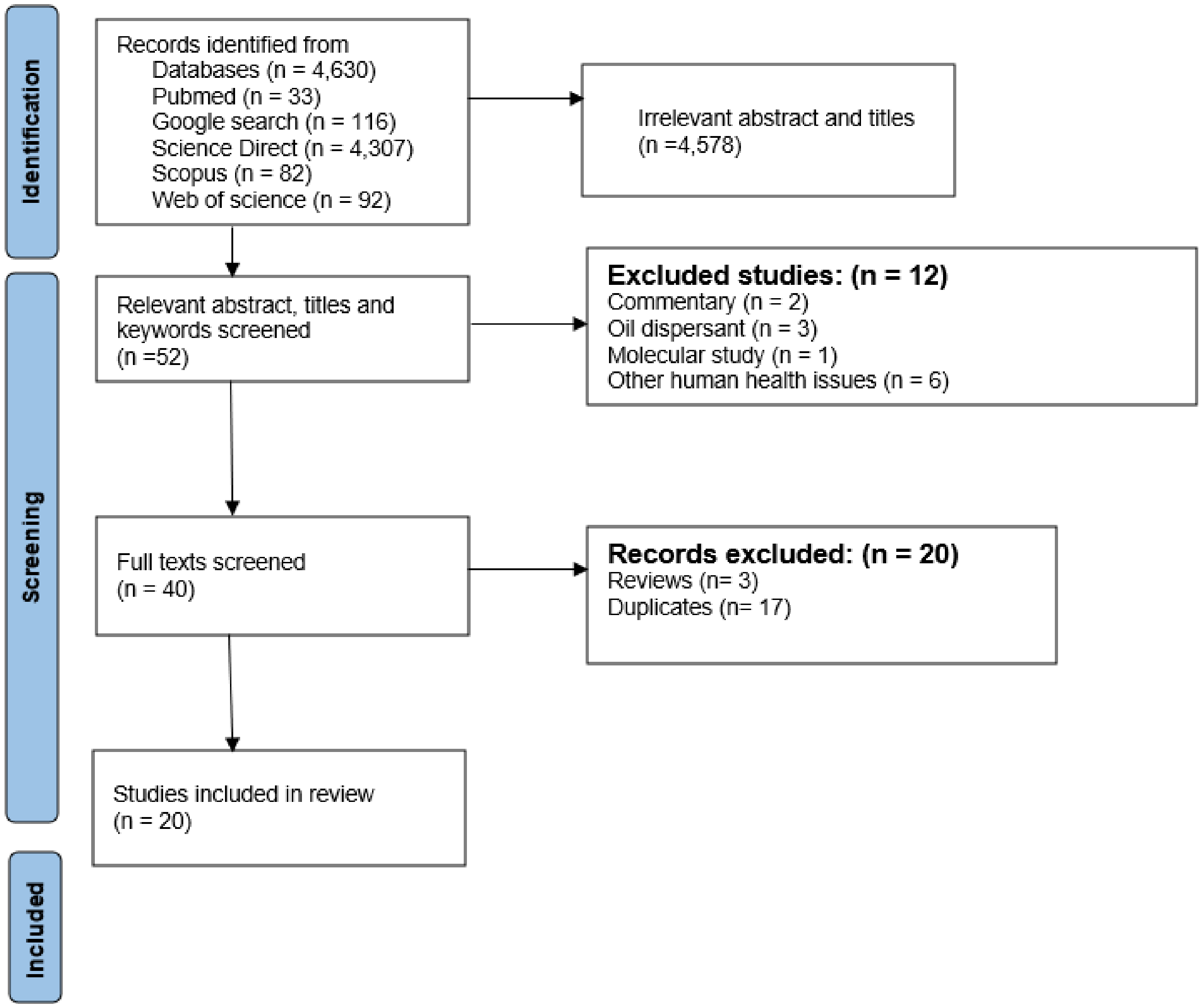

Figure 1. Study selection process using PRISMA flowchart.

According to the main outcome that the selected studies addressed, the results of the selected studies were split up into five categories: Crude Oil Spills; DWH Oil Spill and RH of Clean-up Workers; Hebei Spirit Oil Spill and RH of Clean-up Workers; Tasman Spirit Oil Spill and the RH of Clean-up Workers; and Prestige Oil Spill and RH of Clean-up Workers.

3. Results

3.1. Search Results

In the PRISMA flowchart above (Figure 1), results from the initial searches were 4630 articles, of which 52 articles were assessed for eligibility based on relevant titles and abstracts. After the exclusion of 12 studies not in line with the review focus (Molecular study (n = 1); Commentaries (n = 2); Oil dispersants (n = 3); Other human health issues (n = 6)) and 20 records that fell short of the aforementioned inclusion criteria (3 reviews, 17 duplicates), 20 studies were retained.

The summary of the different crude oil spills reviewed in this paper is shown in Table 1, while the outcomes discussed were classified under crude oil spills and the RH effects of the vulnerable population in Table 2.

3.2. Methodological Analysis

3.2.1. Study Design

Articles utilized in this review were epidemiological studies (cross-sectional (five), prospective cohort (six), follow-up (two), prospective follow-up (one), prospective study (one), case control (one), and comparative study one1)). Others included a survey. Some studies, however, used more than one study design.

3.2.2. Place of Research

The articles used in this review were carried out in 4 countries of the world, namely the United States of America with 11 studies, Spain with 4 studies, Pakistan with 3 studies, and South Korea with 2 studies.

3.3. Analysis of Results

Twenty studies discussed different crude oil spills that have occurred globally. Some of these articles discussed the same oil spill and so were merged, as seen in Table 1. A total of 3 articles focused on the Tasman Spirit oil spill, 11 articles on the DWH oil spill, 2 articles on the Hebei Spirit oil spill, and 4 articles on the Prestige oil spill (Table 1).

The vulnerable population included in this review are the clean-up workers. All the articles selected in this review discussed the relationship between exposure to an oil spill or its pollutants and the respiratory effects on clean-up workers (Table 2).

3.4. Crude Oil Spills

3.4.1. Tasman Spirit Oil Spill (TS Spill)

Three studies gave reports on the Tasman Spirit spill. An oil tanker from Greece, with over 67,540 tons (about 77,745.4 Kilolitres, KL) of Tasman Spirit crude oil, shipwrecked in Pakistan (precisely, the Karachi port channel), and damaged its hull, with a resultant bursting of the tanker. An estimated 35,298 KL (30,000 tons) of crude oil was spilled and spread to the seashores in 2003 [39]. Approximately 11,000 tons of VOCs were released into the atmosphere from the volatile components of crude oil, thereby polluting the air [40,41]. A lot of health concerns were raised among residents and workers at the spill site regarding the presence of the oil split on the coast and the fumes in the air.

3.4.2. Deepwater Horizon Oil Spill (DWH Spill)

Eleven articles used for this review gave reports on the DWH spill. The DWH spill was one of the most destructive oil spill disasters recorded in the United States of America [42]. The spill occurred in 2010 and attracted thousands of clean-up and response workers to the spill site [43–47]. The DWH spill was a result of an explosion on the DWH drilling rig of British Petroleum, which led to the release of approximately 200 million gallons (4,761,905 barrels or about 757,082 KL or 649,645 metric tons) of oil into the Gulf of Mexico [8,48,49]. The spill went on for over 80 days due to failed attempts to cap the well. This led to the contamination of about 225,000 square kilometres of coastal planes from Texas to Florida [50]. This not only affected the health of the response team but also the health and livelihood of those residing in these coastal regions [51].

3.4.3. Hebei Spirit Oil Spill (HS Spill)

Studies from two articles on the HS oil spill are included in this review. The greatest oil spill ever recorded in Korean water was the HS spill [52]. It occurred on the 7th of December 2007 when the carrier, Hebei Spirit conveying an estimated 300,000 tons of oil, hit a barge on the Yellow Sea Coast of Taean County, Korea [53]. This collision resulted in the spill of the Iranian heavy Kuwait Export and Upper Zakum oils. Approximately 12,942.6 KL (an estimated 11,000 tons) of oil was spilled. The oil swiftly covered more than 1000 km of coastal line, destroying biodiversity and the environment that attracted tourists each year [53]. The coastline of the county was severely affected, resulting in the destruction of tourism and fishing industries indefinitely. According to [52], the oil spilled from the HS contained VOCs such as BTEX, PAHs, and heavy metals which can easily be volatilized and absorbed into the human body, causing acute symptoms and debilitating diseases [52].

3.4.4. Prestige Oil Spill

The Prestige oil spill was reported in four articles in this review. In November 2002, the Prestige (oil tanker) capsized, spilling more than (77,123.8 KL) 67,000 tons of bunkered oil, heavily polluting the Galician coast in northwestern Spain [54.55]. The Prestige was a 26-year-old single-hulled tanker sailing to Singapore from St. Petersburg and Ventspils in Russia and Latvia, respectively [56]. The ship suffered serious damages caused by a storm, which led to a leakage of fuel at sea. The Prestige later sank after splitting in two, causing the spilt oil to spread from the northwest coast of Spain to Asturian shores and Cantabria both in Spain and to the Western Pyrenees, more precisely, the Basque country [55]. Exposed residents and fishermen developed health issues including increased bronchial responsiveness [57].

3.5. Crude Oil Spills and Respiratory Health

Of all the 20 articles that reported on the repercussions of crude oil spill on the RH of clean-up workers, 3 articles reported RH consequences in relation to the Tasman Spirit oil spill, 11 studies on the DWH oil spill, 2 articles on the Hebei Spirit oil spill, and 4 studies on the Prestige oil spill.

3.5.1. Tasman Oil Spill and Respiratory Health of Clean-Up Workers

Three articles focused on the RH effects of the Tasman Spirit oil spill on clean-up workers [39–41].

Meo and colleagues conducted a cross-sectional study following the Tasman oil spill into the sea in which a sample of oil spill responders (n = 20) was compared with their matched controls (n = 31) [39]. The study was conducted between the months of August 2003 and August 2004, exposure was assessed based on the duration of being exposed. Clean-up workers participated in the clean-up operations for a minimum of 8 h daily 6 days per week using a piece of cloth as a protective covering for their nose and mouth. Meo et al. compiled information on the anthropometry and pulmonary function parameters via spirometry tests between the exposed and their matched controls and compared these parameters. Their results showed that clean-up workers who were exposed to polluted air caused by the Tasman Spirit oil spill have a marked decrease in their forced vital capacity (FVC) (p = 0.001 *), forced Expiratory Volume in one second, FEV1(p = 0.001 *), forced expiratory flow (FEF25–75%) (p =0.02*), and maximum voluntary ventilation (MVV) (p = 0.001 *) compared to their matched controls [39]. A year later, the same authors performed a follow-up study on the exposed population from the previous study (n =20), comparing the previous values obtained a year before with the current data. Their results showed a significant reversal increase for FVC, FEV1, PEF, FEF25–75% (p = 0.001 *; 0.001 *; 0.02*; 0.02*; and 0.001 *, respectively) [39]. These reduced pulmonary functions were reversed and improved once the exposed individuals were removed from the polluted environment [39].

Health complaints among respondents who partook in the oil spill response operations of the Tasman Spirit oil spill were investigated in a case–control study conducted by Meo and colleagues [40]. This study was performed between July 2003 and December 2004. Interviews and a standardized questionnaire were used to recruit a study group of healthy males (n = 50) on the basis of working at the oil spill site for a minimum of 8–10 h/day, 6 days per week, using a hand-made nose and mouth mask, and these workers were compared with matched controls (n = 50) made up of salesmen, clerical staff, and shopkeepers who lived 15–20 km from the coastal belt. Results on RH complaints as compared with their matched controls were compiled. Higher rates of coughing (about 40%), rhinorrhoea (36%), sore throat (about 30%), malaise (18%), dyspnoea (14%), chest tightness (about 10%), sputum (8%), and wheezing (6%) were observed in the exposed group when compared with the control group [37]. The odds ratio (OR) of sore throat (OR = 6.1; 95% CI: 1.6–23.0; $p < 0.006$ *); malaise (OR = 31.0; 95% CI: 2.0–542.2; $p = 0.0004$ *); cough (OR = 9.6; 95% CI: 2.6–35.2; $p < 0.0002$ *); and runny nose (OR = 14.0; 95% CI: 3.0–62.0; $p < 0.0001$ *) were remarkably higher among the clean-up workers than the controls [40].

The consequences of time of exposure to contaminated air on lung volumes in response workers not protected from the Tasman Spirit oil spill were investigated by a study conducted by Meo and colleagues [41]. This comparative study was also conducted in the same location as the aforementioned article by Meo and colleagues [40]; however, the study population was 31 healthy males who were clean-up workers. These healthy males were matched with 31 males as controls who did not participate in the clean-up operation and resided about 20 km from the coastal belt. Assessment of respiratory health was performed using an electronic spirometer. A written questionnaire was used to gather anthropometric information. The outcome of their study showed that the lung function of the exposed group was significantly affected by the duration of exposure to air pollutants from the Tasman Spirit oil spill. Generally, those who were exposed to the spill had statistically significant reductions in FVC, FEV1, FEF25–75%, and MVV ($p = 0.001$ *; $p = 0.002$ *; and $p = 0.001$ *, respectively). Exposure to these pollutants for less than 8 days had a significant difference in only FVC ($p = 0.001$ *), while exposure to the oil spill pollutants for 8–15 days revealed a statistically significant difference for FVC ($p = 0.05$ *), and exposure to the oil spill pollutants exceeding 15 days revealed notable reductions in FVC, FEV1, FEF25–75%, and MVV in the exposed group relative to their controls ($p = 0.001$ *; 0.001 *; 0.02 *; and 0.002 *, respectively) [41].

3.5.2. DWH Oil Spill and Respiratory Health of Clean-Up Workers

Eleven articles focused on the association between DWH oil spill and RH of oil spill responders [8,42–51].

The acute and chronic health consequences of the DWH oil spill were evaluated in the cohort study that utilized data from the cross-sectional survey and medical contacts of military personnel. The study participants were the US Coast Guard members (oil spill responders, about n = 8700 vs. non-responders, about n = 44,800). Two surveys were performed. The first began on 25 June 2010, while the second survey began on 1 November 2010. Exposure was assessed via inhaling the toxicants, oral route, dermal route, and submersion on an ever/never scale in survey 1, while exposure frequency through the routes was assessed in survey 2 using a 5-Likert scale. Their results, which were reported in terms of adjusted prevalence ratios and adjusted relative risks, showed that there was a statistically significant elevated prevalence ratio (PR)s, which increased with exposure for all three symptoms investigated: cough (PR = 1.6–1.8); wheeze (PR = 2.1–2.3); dyspnoea (PR = 1.8–2.3), as well as an elevated risk (RR(95% CI) for chronic respiratory diseases, asthma, and COPD ((1.0;1.0 to 2.0); (2.0; 1.0–3.0); and (1.4; 0.97 to 1.9)) 2.5 years after exposure [49].

Rusiecki and colleagues carried out a prospective analysis to gain insight into the relationship between exposures to oil spills and RH risks in US Coast Guard personnel (n

= 45,193) using medical encounter data, approximately 2.5 years before the spill and 5.5 years after the spill, from 1 October 2007 to 30 September 2015 [51]. Comparisons were performed based on worker vs. non-worker; the worker comparison (ever contacted oil vs. never contacted oil, ever inhaled oil vs. never inhaled oil, ever in the same premise with burning oil vs. never, and effects of both oil and dispersants) used data obtained from self-reported exposure from two previous studies. These were used to assess exposure. Their results revealed that for worker/non-worker comparisons, weak raised adjusted hazard ratios (aHRs) were recorded; however, when comparing among workers, stronger risks were associated with exposure to crude oil. Elevated risks for all sinusitis; unidentified long-term sinusitis; COPD and other allied conditions; shortness of breath; and RH issues were observed in responders who were exposed to crude oil through inhalation [(aHR; 95% CI): (1.5; 1.1–2.1); (1.6; 1.1–2.0), (1.4; 1.0–2.1), (1.3; 1.0–1.7)]. Elevated risks were observed in morbidities categorized as asthma and reactive airway diseases, including the specific condition, asthma, dyspnoea, and the general categorization of long-term RH effects [(aHR; 95% CI): 1.2; 1.0–1.4), (1.4; 1.0–2.3), (1.5; 1.0–2.5), and (1.2; 1.0–1.4)]. Responders who were exposed to these two (crude oil and dispersant) had positive associations with elevated risk for dyspnoea (HR = 2.2; 95% CI: 1.0–5.0) [51].

The adverse effects of the DWH oil spill on response workers along Louisiana coastal areas were evaluated by D'Andrea and Reddy. In their study, which was retrospective as well as cross-sectional in nature, 130 exposed and 117 non-exposed subjects were recruited. They gathered information from medical charts and self-reported somatic symptoms. Results showed that the blood profiles, liver enzymes, and somatic symptoms were altered. Somatic symptoms including headache 77%, dyspnoea 71%, skin rash, chronic cough 52%, and chest pain 38% were some of the most reported [50].

The long-term health effects of the DWH oil spill were also assessed by D'Andrea and Reddy among workers who took part in the clean-up operations in the follow-up study. Medical records from 88 subjects were reviewed (44 clean-up workers and 44 non-exposed) during the initial and 7-years-later follow-up visits. Results from the follow-up visit 7 years later revealed that respiratory symptoms persisted, and newer symptoms developed. Assessment of these clean-up workers revealed that 91% of those exposed to the oil spill had a progressive decline in their RH and developed chronic rhinosinusitis from their initial baseline assessment. Additionally, 45% of those exposed showed new symptoms not recorded in their initial visits (chronic reactive airway dysfunction syndrome). Pulmonary functions had progressively worsened, as incidences rose from 0% in the initial study to also include severe pulmonary function abnormalities at 9%. Totals of 48%, 34%, and 16% were incidences of normal pulmonary function, mild pulmonary abnormality, and moderate pulmonary abnormality in the 7-year follow-up study, as against 84%, 9%, and 6.8% in the initial study, respectively. Other respiratory symptoms include shortness of breath at 84%, chronic cough at 55%, chest pain at 34%, nasal obstruction at 23%, and difficulty in breathing at 9% [42].

Due to the massive disaster that occurred with the DWH oil spill, 8500 United States Coast Guards were deployed to the scene of the incident to take part in the clean-up operations. A cross-sectional study was conducted, and personnel members were interviewed via survey [8]. Of the 4855 personnel that completed the survey, 55% and 22% were exposed to the spill and the oil dispersant, respectively. The assessment of the spill was based on the timing, duration, and job description at the spill site, as well as crude oil exposure, oil dispersant, and fumes from the exhaust. The most common symptom was a cough (19.4%). Others were dyspnoea (5.5%) and wheeze (3.6%). There was an association between increased deployment duration and the likelihood of cough (≥2 months: Prevalence ratio (PR): 2.1; 95% CI:2.0–3.0 Ptrend< 0.01), dyspnoea (≥2 months: PR: 1.9; 95% CI: 1.3–2.7; Ptrend< 0.01), and wheeze (≥2 months: PR: 2.0; 95% CI: 1.0–3.0; Ptrend: 0.04) in the pre-capping period. During the post-capping period, this same pattern was recorded for cough (≥2 months: PR: 2.5; 95% CI: 1.7–3.7 Ptrend< 0.01) and wheeze (≥2 months: PR: 3.1; 6 95% CI: 1.4–7.2; Ptrend: 0.03). There were increased PRs for cough (PR = 1.9), dyspnoea

(PR = 2.6), and wheeze (PR = 2.7) for any exposure to oil. Elevated frequency of inhaling the spilled oil was correlated with an elevated possibility of these three respiratory symptoms. Workers who had contact with the oil dispersant also had a homogenous pattern recorded for cough and dyspnoea. A sub-analysis was performed between the responders who were exposed to spilled oil only and those exposed to the combination of oil and oil dispersant and compared with those who were not exposed. Those who reported being exposed to oil alone had increased PRs for cough, dyspnoea, and wheeze [(PR; 95% CI): (1.7; 1.4–2.0), (2.0; 1.0–3.0), and (2.2; 1.4–3.6)], respectively. Stronger PRs in connection with cough, dyspnoea, and wheeze [(PR; 95% CI): (2.7; 2.3–3.2), (5.0; 3.0–7.0), and (5.1; 3.2–8.1)], respectively, were recorded among workers who were exposed to the combination of crude oil and its dispersants [8].

Gam and colleagues conducted a study 1–3 years after the DWH incident on oil spill response and clean-up (OSRC) workers to assess the relationship between six oil spill experiences and their pulmonary function. A complete case analysis was performed on 4806 clean-up workers from the Gulf Long-Term Follow-up (GULF) study [43]. These participants had their spirometry test performed and were up to date with their information on exposures and confounders. Questionnaires were used in gathering data on the oil experiences. Those who were exposed to oil-spill-related events included those with chemical-smelling jobs; dermal or clothes contact with oil/tar/oily water; chemical-wet bodies or clothes; those who stopped work due to heat; those who worked any oily-flora/fauna- or dead-animal-recovery jobs; and those not doing any regular job. These respondents were categorized independently for each oil spill event, implying that response workers could be labelled as exposed for one event and unexposed for another [43]. The unexposed group was made up of those that did not fall into any of these categories. Their results revealed that those who smelled chemicals had elevated FEV1 and FVC values compared to unexposed workers (Mean difference (MD): 30 mL; 95% CI: −3, 64 and 30 mL, 95% CI: −9, 70), although the relationships were weaker in analyses including workers with imputed data. Workers with jobs involving oily-flora/fauna or dead-animal recovery had significantly lower FEV1, FVC, and FEV1/FVC [(MD;95% CI): (−70 mL; −105, −34); (−56 mL; −97, −15) and (−0.6%; −1.0, −0.2)] compared to unexposed. These associations were related but attenuated for workers with imputed data for FEV1, FVC, and FEV1/FVC [(MD;95% CI): (−53 mL; −84, −22); (−45 mL; −81, −9) and (−0.44%; −0.80, −0.07)], respectively. There were no other associations between lung volumes (FEV1; FVC and FEV1/FVC) and other oil spill events (dermal or clothes contact with oil/tar/oily water [MD (95% CI): −23 (−58, 12); −18 (−59, 23) and −0.13 (−0.6, 0.3)]; body or clothes ever became soaked with chemicals [MD (95% CI): 17 (−18, 50); 4 (−37, 44); and 0.4 (−0.02, 0.8)]; those who had to stop working because of heat [MD (95% CI): −16 (−49, 18); −23 (−62, 16) and 0.14 (−0.3, 0.5)]; and those potentially not doing any regular job [MD (95% CI): 28 (−19, 75); 34 (−21, 89) and 0.2 (−0.4, 0.7))] [43].

Gam and colleagues conducted a study to ascertain the association between exposure to oil spills via clean-up exercises and pulmonary function 1–3 years after the DWH incident [44]. A prospective cohort of adults recruited during the GuLF study and data from this study were used. Spirometry for 7780 adults who partook in DWH clean-up operations and non-workers were evaluated. Different comparisons were performed between varying groups of workers: workers vs. non-workers, decontamination workers vs. support workers, and workers with a high potential of exposure to combustion of oil/gas vs. unexposed workers. The lung function of these groups was assessed using spirometry. Their results showed no differences between workers and non-workers. Among workers, small decrements in FEV1 (Beta: −70 mL, 95% CI: −130, −10) were recorded in decontamination workers when compared to support workers. Reduced pulmonary functions were also recorded in workers with high potential exposure to burning oil/gas compared to unexposed workers: FEV1 and FEV1/FVC [(Beta; 95% CI): −180 mL; −320, −50) and (−1.9%; −3.5, −0.4), and an elevated risk of having a FEV1/FVC in the lowest tertial (PR: 1.4, 95% CI: 1.0–2.0)] [44].

A prospective cohort study was reported with the aim to evaluate the association between total hydrocarbon (THC) exposures attributed to oil spill clean-up workers and lung function 1 to 3 years after the DWH disaster. A prospective cohort of adults recruited during the GuLF study and data from this long-term follow-up study were used, including adults who worked as response workers and others who were safety trained, though they were non-workers. Data with two acceptable spirometry tests were analyzed from 6288 workers. A job exposure matrix was used to estimate the THC exposure levels [45]. A pre-bronchodilator spirometry test was performed to analyze FVC, FEV1, and FEV1/FVC. Their results showed that more workers with higher THC exposure lived close to the affected counties compared with the less exposed (8.0% vs. 6.0%; $p < 0.001$ *). Those with more THC exposure likely took part in previous oil spill clean-up operations compared to those with lower THC exposure (10.0% vs. 7.0%; $p < 0.001$ *). There were no distinct differences observed in FEV1 or FVC between maximum THC levels and pulmonary function by ordinal THC level. Though there was a reduction in FEV1/FVC in workers with the greatest exposure to THC level compared to workers with the lowest exposure, this reduction was not statistically significant (MD: −0.6%, 95% CI: −1.3 to 0.003%). There was therefore no relationship between exposure to THC and the pulmonary function of those who participated in the clean-up operations within 3 years of the spill [45].

In addition, there was a slight attenuation, similar to the primary analysis, in the estimated difference in FEV1/FVC for the highest THC exposure level versus the lowest (MD: −0.6%, 95% CI: −1.4 to 0.2) among workers in the analytic sample with no burning oil/gas exposure (n = 5603) [45].

Another study was performed to assess the relationship between estimated $PM_{2.5}$ only from combustion and the flaring of oil and gas and the dynamic lung volumes measured 1–3 years following the DWH incident. Using participants from the GuLF STUDY, 2316 clean-up workers (burning-exposed workers (n = 518) and referent group (n = 1798)) were selected for this study based on having 3 spirometry tests recorded or by an expert's decision, plus being checked for all confounders that participated in clean-up of the spills [48]. The estimation of the exposure to $PM_{2.5}$ from the combustion of these toxicants was from 15 May to 15 July 2010. FEV1, FVC, and FEV1/FVC were evaluated, and their results showed that a higher cumulative daily maximum $PM_{2.5}$ exposure was significantly associated with lower FEV1 (p-trend = 0.04) and FEV1/FVC (p-trend = 0.01). Workers involved in the combustion of the oil and gas had lower pulmonary function parameters FEV1 and FEV1/FVC when compared with workers who did not take part in the burning of the pollutants or were near the burning site [−166.8 mL, 95% CI: −337.0, 4.0 and (−2.0, 95% CI: −4.0, 0.2), respectively]. There was also a non-significant decrement in FVC (high vs. referent: −121.0, 95% CI: −320.0, 78.0; p-trend = 0.4). The same relationships were observed for average daily maximum $PM_{2.5}$ exposure. Inverse associations were also observed in analyses stratified by smoking and time from exposure to spirometry as well as those restricted to workers without pre-spill lung disease. A sub-group analysis revealed a significant trend between average daily maximum exposure and FEV1 (p-trend = 0.02*) and significantly lower FEV1 (−230.0 mL, 95% CI: −430.0, −25.0) among the never-smoking workers in the high-exposure group, as well as a consistently lower FVC among never smokers with higher average and cumulative daily maximum exposures. The association between cumulative daily maximum exposure and FEV1/FVC was statistically significant (p-trend = 0.01 *), accompanied by insignificantly lower FEV1/FVC in the high-exposure group (−3.0%, 95% CI: −6.0, 0.1) in the never-smoked sub-group [48] as seen in Table 2.

Lawrence and partners, in their study that assessed the pulmonary function in clean-up workers 4–6 years after the spill, utilized the prospective cohort GuLF Study [46]. Participants who were recruited had completed two spirometry test sessions 1–3 years and 4–6 years after the spill (n = 1840); (worker vs. non-worker: 270 vs. 1570, respectively) and had FEV1, FVC, and FEV1/FVC determined. The classification of these participants was based on their levels of exposure to THC: response (highest exposure), operations, cleanup on water, decontamination, cleanup on land, and support (lowest exposure). The classification was also based on their exposure to burning oil/natural gas. Participants who worked multiple jobs were classified by their single highest exposed job/task. Their results showed that those with the greatest exposures 1–3 years after the spill initially had a decline in their pulmonary function. This group of clean-up workers, however, had the greatest improvement in their pulmonary function 4–6 years after the spill. Workers with THC exposure 1–2.99 ppm and ≥3 ppm had greater FEV1 than those with ≤0.3 ppm (β: 110 mL, 95% CI: 20, 200) and (β: 120 mL, 95% CI: 5, 230), respectively. Those in higher-exposed jobs displayed greater improvement in FEV1 between visits: cleanup on water (β: 140 mL, 95% CI: 35, 250), operations (β: 130 mL, 95% CI: 30, 230), and response (β: 150 mL, 95% CI: 40, 260), as compared to support workers. Greater FEV1 improvement was also associated with a higher versus the lowest level of THC exposure: 1–2.99 ppm (β: 130 mL, 95% CI: 60, 210) and ≥3 ppm (β: 200 mL, 95% CI: 110, 300). They noted that the decrease in the pulmonary functions observed immediately after the spill was no longer evident 4–6 years later, with the greatest improvement noticeable among those with the greatest exposures [46]. A detailed result of the studies is shown in Table 2.

Lawrence et al. performed a study to evaluate the primary inhalational risks and threats faced by clean-up workers after the DWH oil spill. These response workers were exposed to chemicals by nature of their job class, such as the mixture of Benzene, Toluene, Ethylbenzene, o-, m-, and p-Xylenes, and n-Hexane (BTEX-H) chemicals, the individual chemicals that make up the BTEX-H, and $PM_{2.5}$ from burning oil and gas. Using data from the GuLF Study, a cohort of about 24,610 workers (19,020 clean-up workers; 5590 non-workers) were recruited [47]. The analysis focused majorly on approximately 19,000 workers who, prior to the spill, had no asthma, but had detailed information on exposures, outcomes, and covariates. Asthma was defined by both self-reported wheeze and physician-diagnosed asthma. Model estimates were used to assign $PM_{2.5}$ to participants, while THC and BTEX-H based on measurement data and work histories were assigned to participants. Their results revealed that the clean-up workers had a greater risk of developing asthma than non-workers (RR: 1.6, 95% CI: 1.4–2.0). Increased asthma risk was associated with higher estimated THC exposure levels ($p < 0.0001$ *), increased exposure to individual BTEX-H, and the combination of these chemicals of 1.5 (95% CI: 1.4–1.6). Associations were less obvious, with fewer cases for only physician-diagnosed asthma [47], as seen in Table 2.

3.5.3. Hebei Spirit Oil Spill and Respiratory Health of Clean-Up Workers

Two studies recorded the association between the Hebei Spirit oil spill and the RH of clean-up workers [52,53].

Gwack and colleagues conducted a survey on 2624 members of the military including Hebei Spirit oil spill responders and 574 non-participants from 4 January to 19 February 2008 [52]. Health symptoms in this study were self-reported, and the respiratory symptoms include cough, sputum, rhinorrhoea, sore throat, and dry mouth. A structured self-assessment questionnaire was used to collect the data. Their results showed that acute symptoms were significantly more prevalent following the prolonged days of the clean-up operation, excluding red skin as a symptom. Officers who partook in the clean-up activities had more respiratory symptoms than those who did not, described as follows: cough ($p = 0.02$ *), phlegm ($p < 0.01$ *), and malaise ($p = 0.04$ *). Smokers who were clean-up workers had greater cough prevalence (p = 0.02 *). Clean-up workers who did not wear their masks well, although they wore other personal protective devices, had a greater prevalence of symptoms such as headache ($p < 0.01$ *) and pharyngitis ($p < 0.01$ *). It was also observed that the younger aged military personnel members had fewer symptoms than the older aged groups [52], as seen in Table 2.

Sim et al. also investigated the acute health problems in response workers of the Hebei Spirit oil spill by surveying 846 people that participated in the oil spill response operations from the 13th to 20th of the month of December 2007 in Wonbuk Town [53]. Information regarding the clean-up operations was obtained including how many hours worked in a day, how many days worked, personal protective equipment utilization, and health information. Their results showed that the number of days worked was related to an increased risk of respiratory symptoms, OR 2.1 and 95% CI: 1.6–3.0 for more than 7 days. They also reported that not protecting the respiratory system from these pollutants was linked to the development of respiratory symptoms (OR: 1.5 (1.3–1.8)). The reported respiratory symptoms include pharyngitis, cough, and respiratory difficulties [52,53], as seen in Table 2.

3.5.4. Prestige Oil Spill and Respiratory Health of Clean-Up Workers

Four studies were reported on the RH effects of exposure to Prestige oil spill on clean-up workers in Spain [54–57].

Rodriguez–Trigo and colleagues performed a survey evaluating the RH effects and the debilitating effects of the Prestige oil spill on the chromosomes of response workers 2 years after being exposed to the spill. Although the number of fishermen in the cooperative who were exposed to the oil spill due to partaking in the clean-up activities was n = 1119 and the non-exposed group was n = 577, those that finally took part in the study for the exposed group were n = 501 and the non-exposed group n = 117 from both cooperatives in the Cantabrian coast of Spain. The exposed fishermen with the greatest exposures participated for at least 15 days in the clean-up operations, for at least 4 h a day. Interviews, clinical testing which included spirometry, methacholine challenge, assessment of biomarkers in exhaled breath condensate, and others were performed. The results revealed an elevated risk for lower respiratory tract conditions (risk difference (RD), 8.0 [95% CI: 1.0–15.0]) in the exposed. Additionally, elevated markers of airway injury were observed in the breath condensate of the exposed group. Pulmonary function, however, did not differ remarkably between the two groups [54], as seen in Table 2.

Suarez et al. assessed the exposure conditions and acute health effects in clean-up workers exposed to the Prestige oil spill [56]. The response workers were seamen, fishermen, bird cleaners, volunteers, and paid workers. Four hundred respondents were recruited from each region via a simple random sampling of those involved in the clean-up and stratified by the type of worker and number of working days. There was a statistically significant relationship between exposure to crude oil from the Prestige Spirit oil spill and throat and respiratory problems (OR: 10.4 [95% CI 4.0–27.4] $p < 0.001$ *) [54], as seen in Table 2.

Zock et al. performed a longitudinal study to assess the persistence of RH consequences 5 years after the clean-up activities [55]. This was conducted as a follow-up study using the information obtained from the baseline study [54]. Telephone interviews were used to successfully recruit about 470 exposed and 160 non-exposed fishermen. The recruitment of the exposed group was based on carrying out clean-up work for at least 35 days, for 5 h per day. It was also based on not using or rarely using face masks, and performing a minimum of five different clean-up activities. Workers that did not keep to these criteria were termed the moderately exposed group. Zock et al. result showed that the prevalence of lower respiratory tract symptoms was higher in the exposed group (RR 1.4, 95% CI 1.1–2.0). These lower respiratory symptoms included wheezing, dyspnoea, coughing, and sputum production. There was a corresponding increase in the risk of having chronic respiratory symptoms with an increase in the degree of exposure, and this was observed at both the initial study and follow-up: RR: 2.0 (95% CI 1.0–3.0) and 3.0 (95% CI 1.8–6.0) for moderately and highly exposed, respectively, as compared to those without any symptoms. These findings revealed that respiratory health consequences could persist even after 5 years of exposure [55], as seen in Table 2.

In the same vein, another longitudinal study follow-up was conducted by [57] in 2008/2009. This time, the aim was to assess the persistence of the functional and biological RH effects 6 years after clean-up activities. This study looked at the clean-up workers (fishermen) who were exposed in 2002/2003 following the baseline survey performed in 2004/2005. Using similar methodologies as in the initial evaluation, 230 clean-up workers who never smoked were recruited as the exposed group and studied with 87 non-exposed clean-up workers who never smoked. Due to the loss of the follow-up study, the reason being that the non-exposed group had minimal respiratory symptoms at the baseline survey, information was gathered from about 160 exposed and 60 non-exposed fishermen. Their results showed that in the non-exposed group, the pulmonary function, hyperresponsiveness of the bronchi, growth factors, and respiratory biomarkers of oxidative stress levels had remarkably declined compared to the exposed group. The parameters of respiratory health were either the same or better in clean-up workers as compared to non-exposed, particularly the FEV1/FVC and the FEF25–75% that were remarkably elevated in the exposed after controlling for potential confounding variables, revealing that long-term RH consequences were not detected 6 years after the oil spill and in the 4-years follow-up [57], as seen in Table 2.

The methodological quality of the different studies used in this review is summarized in Table 3. The total methodological quality assessment of the studies was moderate with a mean (± SD) NOS score of 5.9 ± 2.2 (11 being the maximum achievable score). Most studies clearly assessed outcomes (75%) and most (75%) studies controlled for potential confounding variables. Most of the studies met the criteria for the selection of the comparison group (85%). However, three studies did not meet these criteria (cross-sectional studies) [52,54,56].

Table 3. Quality Assessment Using Newcastle–Ottawa Scale for Observational Studies [38].

		Selection						Comparability	Outcome			Remark
S/N	Reference	Representativeness	Selection of Comparison Group	Ascertainment of Exposure	Precision of Exposure Dose Ascertainment	Ascertainment of Exposure Performed Prospectively or Retrospectively	Demonstration that Outcome of Interest was not Present at start of Study, OR Baseline Assessment	Adjustment for Confounding (Rendering Comparability of Cohorts on the Basis of the Design or Analysis)	Assessment of Outcome	Was Follow-Up Long Enough for Outcomes to Occur?	Adequacy of Follow-Up of Cohorts	Remark Risk of Bias (High, Medium, Low)
1.	[39]	0	+	+	0	0	+	++	+	+	+	9
2.	[40]	0	+	+	0	0	0	++	+	0	0	5
3.	[41]	0	+	+	0	0	0	++	+	0	0	5
4.	[49]	+	+	0	0	+	+	0	+	+	+	7
5.	[51]	+	+	0	0	+	+	+	+	+	+	8
6.	[50]	+	+	+	0	0	0	0	0	0	0	3
7.	[42]	0	+	0	0	+	0	0	0	+	0	3
8.	[8]	+	+	+	+	+	0	+	0	0	0	6
9.	[43]	+	+	0	0	+	0	++	+	0	0	6
10.	[44]	+	+	+	0	+	0	++	+	0	0	7
11.	[45]	+	+	+	+	+	0	++	+	0	0	8
12.	[48]	+	+	+	+	+	+	++	+	0	0	9
13.	[46]	+	+	0	+	+	0	++	+	+	0	8
14.	[47]	+	+	0	0	+	0	++	+	0	0	6
15.	[52]	0	0	+	0	0	0	0	+	0	0	2
16.	[53]	0	0	+	0	0	0	++	0	0	0	3
17.	[54]	+	+	0	0	0	0	++	+	0	0	5
18.	[56]	+	0	0	0	0	0	0	+	+	0	3
19.	[55]	+	+	+	0	+	0	++	0	+	+	8
20.	[57]	+	+	0	0	+	0	+	+	+	+	7

+ means 1 point; ++ mean 2 points.

4. Discussion

In this systematic review that summarized the association between oil spills and the respiratory health of the clean-up workers, twenty studies examining this relationship were identified with search itineraries in different scientific databases. Due to the heterogeneity in the methodologies utilized in the different studies to assess the exposure and outcome variables, we did not do a meta-analysis. This heterogeneity included differing pollutants, varying sites of exposure, sources, and application of varying study designs [58]. Therefore, this systematic review showed the diversities in the methodologies used for evaluating outcomes in relation to exposure variables. Thus, questionnaires, interviews, spirometry, etc., were used in making assessments. Some of the studies were longitudinal studies, prospective cohort studies, case–control studies; hence, temporality and causality were assessed. Meanwhile, others were cross-sectional studies, thus inhibiting an assessment of temporality and causality [59].

In this systematic review, four different oil spills were discussed, namely the Tasman Spirit, DWH, Hebei Spirit, and Prestige oil spills in the period under review. Most of the articles were on the DWH oil spill and RH of response workers (55%), while articles on the Hebei Spirit oil spill and RH of response workers were the least common (10%). Even though the oil spilt had different components, they all had similar negative impacts on the environment and the respiratory system.

Clean-up workers consist of volunteers, military personnel, paid workers, residents, etc., that helped in remediating the environment after an oil spill. Different approaches were used to assess the RH of clean-up workers such as spirometry, methacholine challenge, and self-reported data via questionnaires and interviews. A spirometry test was used to assess the respiratory health of the response workers in nine studies, while self-reported data, interviews, questionnaires, or medical records were used to assess the respiratory health of clean-up workers in eleven studies. Most of the studies utilized interviews and questionnaires to characterize exposure to crude oil spills by defining the duration of exposure, use of protective gears, distance from the spill site, etc. Very few studies made use of actual estimates of the pollutants from the crude oil. This review focused on occupational exposure to crude oil spills and their respiratory health effects. The quality of the articles used in this review was evaluated using the NOS for observational studies based on ROB [38], as shown in Table 3. Five articles had high ROB because they had a score below 5 [42,50,52,53,56], while the remaining 15 articles had their ROB ranging from moderate to low because their scores ranged from 5 to 9 [8,39–41,43–49,51,54,55,57].

The respiratory abnormalities associated with exposure to crude oil spills ranged from acute respiratory symptoms and diseases to chronic respiratory symptoms and diseases. Oil spills have occurred globally on varying scales and affect the respiratory system in different ways. Oil can be spilled into the sea or land, which can result in aerosol formation as it evaporates. Oil spill can also result in explosions, thereby resulting in the release of thick black fumes into the atmosphere. Several studies reviewed in this article recorded the respiratory symptoms and diseases associated with crude oil spills in the short and long term. The severity of the respiratory symptoms and diseases is dependent on the duration of the exposure, the use of protective gear, the magnitude and frequency of the exposure, the distance from the polluted site, and the population that is exposed to the oil spill pollutants. The clean-up workers were exposed to the oil spill for at least 8 h per day for several days and used some form of protective gear [39].

The respiratory health in the studies was assessed with the use of spirometry tests, which is the basic test to measure pulmonary function, self-reported data using questionnaires and/or interviews, and medical records. Nine articles assessed the respiratory health of the clean-up workers using the spirometry test [40,41,43–48,57]. Spirometry measurements assess lung volumes and flows, and they describe the consequences of obstruction or restriction on lung volumes [39]. They are used widely in epidemiological studies to investigate the history and causality of occupational and environmental pulmonary diseases [39]. Self-reported data using questionnaires, interviews, and medical data were observed in eleven studies. These means of assessing respiratory health has its limitation as respondents may or may not give accurate information (recall bias) on the respiratory symptoms, thereby influencing the respiratory findings.

Strong associations were recorded between oil spills and the RH of the clean-up workers. Fifteen articles showed significant associations with oil spills, their constituents, and the RH of the response workers, indicating that exposure to oil spills can be detrimental to the respiratory health of clean-up workers. Three articles recorded only the prevalence of respiratory symptoms observed with exposure to oil spills. Most spills occur at sea, and the mechanical disruption of the ocean surface leads to the formation of sea spray droplets, which are released into the atmosphere [22]. The aerosolized PM carries toxic compounds from the spills (e.g., PAHs) which may be airborne and transported as droplets. These oils may also be volatilized and may release other pollutant gases, which when inhaled cause adverse respiratory health effects, as seen in the various studies used in this review [22].

Most studies in this review recorded a change in respiratory health either as decline in the function of the lung parameters or the presence of respiratory symptoms reported by the study participants because of their exposure to oil spills during clean-up work. However, two studies by [46,57] had contrasting views. They both had follow-up studies for the DWH oil spill and the Prestige oil spill, respectively, and still had similar findings. Clean-up workers who at the initial study showed significant associations between the oil spill and respiratory health effects in terms of reduced pulmonary functions later had better and improved pulmonary function 4–6 years after the spill in the case of [46] and 6 years after the spill as recorded by [57]. There was no significant difference between the lung volumes and other oil spill experiences, except for workers who had the job of flora and fauna recovery compared to the unexposed [43]. There was also no significant relationship between the worker and non-workers of the DWH oil spill [44]. One of the studies recorded in this review showed evidence of no difference between the lung function of the oil spill responders and the exposure to THC from the DWH oil spill [45]. There was also no difference between the worker and non-worker comparison when assessing their lung functions [45]. Although workers involved in combustion of oil and gas had lower lung volumes when compared to the non-exposed, it was not statistically significant [48]. Pulmonary function likewise did not differ remarkably between the exposed and non-exposed groups [54].

Explosions secondary to oil spills may also result in the release of toxicants, which can also negatively impact the respiratory health of the oil spill responders. The burning of crude oil results in the release of thousands of volatile organic compounds, particulate matter ($PM_{2.5}$, $PM_{0.1}$) which is inhaled and can adversely impact the respiratory system [60]. These ultrafine and fine particulate matter can become deposited in the alveoli across the blood–brain barrier, induce inflammatory responses, and generate reactive oxygen species, leading to acute respiratory infections, COPD, etc. [32]. An article reviewed in this study took into consideration the exposure to burning at the spill site and its effect on respiratory health, and this showed a strong association as evidenced by the reduced lung function [48].

Some of the respiratory health outcomes recorded were acute respiratory diseases including cough, sinusitis, malaise, sore throat, chest pain, etc., and some were chronic respiratory symptoms and diseases including wheeze, cough, dyspnoea, asthma, and COPD. This evidence shows the detrimental effects of exposure to crude oil spills or its constituents on the respiratory system [8,39–44,47–56]. This may be a result of the dose of the toxicant; the frequency, magnitude, and period of exposure; and the age of those exposed [61]. Clean-up workers, which make up part of the vulnerable population, may develop more severe respiratory symptoms and diseases when exposed to oil spills and their constituents because of their individual susceptibilities ranging from prolonged exposure to contact with the pollutants during clean-up work [62–64].

Although this systematic review focused on the RH consequences of crude oil spills on response workers, crude oil spills can affect virtually everyone and every organ system in the body. The pollutants generate ROS, which results in an elevated transcription of pro-inflammatory mediators through intracellular oxidative stress. Increased ROS results in the depletion of cellular antioxidants, which will consequently result in the destruction of the Deoxyribonucleic acid (DNA), protein, and cellular organelles [32]. These changes result in the alteration of the protein and fats formation, protein folding, and assembling, leading to toxicological effects in all the organs, resulting in cardiovascular diseases, reproductive health abnormalities, chromosomal abnormalities, skin disorders, ocular manifestations, neurological disorders, endocrinological disorders, etc. [32].

This review provides administrators, researchers, environmental health authorities, public health specialists, and all stakeholders with the necessary information regarding the consequences of crude oil spills on the RH of clean-up workers. This review is limited by the methods used in assessing exposure and outcome variables in some of the studies, for example, by using interviews and questionnaires which may encourage recall bias. Data collected via these means may result in the provision of unreliable estimates of the exposure and outcome variables. However, the number of those interviewed helped the results [59]. Overall, consistent results were obtained from these studies, with few exceptions, providing acceptable evidence of the negative impacts of crude oil spills on the RH of clean-up workers.

5. Challenges and Recommendation

Considering the effects of crude oil spills on the RH of clean-up workers globally, we found few studies on the topic, especially in developing countries. We recommend more studies be carried out on this topic. A cross-sectional study design was used in some of the studies we reviewed. We recommend that more prospective longitudinal studies be carried out. The longitudinal study design is useful in evaluating the association between risk factors and the development of diseases, as well as the outcome of treatment over periods of time. It also allows for causality and temporality to be ascertained [65]. Cross-sectional studies, on the other hand, do not infer causality and chronicity of health-related events. Furthermore, components of crude oil and how each of them affects the respiratory health of the vulnerable population should also be researched to give better insight into their individual effects. Quantitative determination of effects should also be used for exposures in future studies. We also recommend that more studies be conducted on other vulnerable populations such as children, women, pregnant women, the elderly, etc.

6. Conclusions

This systematic review has shown that clean-up workers are generally exposed to high levels of pollutants from crude oil spills following clean-up operations. This review also shows that exposure is associated with respiratory diseases. Therefore, there is a need to ensure that research-driven policies and measures are put in place to reduce global oil spillage. Efforts are needed to monitor oil spills and identify their main sources by promptly tackling them in order to reduce oil spills to the barest minimum, with a concomitant reduction in respiratory health effects of clean-up workers. Legislations should also be enforced. There is an urgent need for an integrated approach and effective strategies to reduce this exposure, thereby controlling morbidities associated with it.

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List of Abbreviations

CS	Cross-sectional Study
CC	Case Control
PS	Prospective Study
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
BTEX-H	Benzene, Toluene, Ethylbenzene, o-, m-, and p-Xylenes, and n-Hexane
VOCs	Volatile Organic Compounds
PAHs	Polycyclic Aromatic Hydrocarbons
SO_2,	Sulphur dioxide
NO_2	Nitrogen dioxide
$PM_{2.5}$	Fine Particulate Matter
$PM_{0.1}$	Ultrafine Particulate Matter
WHO	World Health Organization
DALYS	Disability Adjusted Life Years
COPD	Chronic Obstructive Pulmonary Disease
PRISMA	Preferred Reporting Items for Systematic Review and Meta-Analysis
IAP	Indoor Air Pollution
AAP	Ambient Air Pollution
FEV1	Forced Expiratory Volume in one second
MBPT	Methacholine Bronchial Provocation Test
FEF	Forced Expiratory Flow
MVV	Maximum Voluntary Ventilation
DWH	Deep Water Horizon
OSRC	Oil Spill Response and Clean-up Workers
HS	Hebei Spirit
TS	Tasman Spirit
DNA	Deoxyribonucleic acid
ROS	Reactive Oxygen Species
MD	Mean Difference
RD	Risk Difference
SES	Socio-economic status
KL	Kilolitres
SHS	Secondhand smoking
RH	Respiratory health
aHR	Adjusted Hazard Ratio

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