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Review article

Mapping research on resource extraction and health: A scoping review

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ABSTRACT

Current research has been described as inadequate to understand and manage complex social and ecological influences of resource extraction on health. We conducted a scoping review of research on mining or oil & gas extraction and health, to identify patterns and gaps in existing scholarship. Journal articles, peer-reviewed books and book sections published 1995–2015 in English were included, including research on extraction and transport, but not processing, of resources. Based on titles and abstracts, we characterized documents by sector, affected population, health outcome, impact pathway, study objective, methodology and geographic focus. Of 2797 documents that met inclusion criteria, 85.6% focused on mining and 15.0% on oil & gas. The most common affected population was workers (67.9%), followed by surrounding communities (22.3%). The majority of documents (86.1%) characterized health impacts, while 11.4% described interventions. Methods were typically quantitative (84.0% vs. 4.7% qualitative) while impact pathways focused on direct toxic exposures (58.3% vs. 11.2% for ecosystem change and 3.8% for social determinants). Most sources (65.8%) focused on high income or upper-middle income countries. These patterns suggest a need for methodological pluralism, intervention-focused studies and attention to complex social-ecological system dynamics and neglected populations, especially in the global South.

1. Introduction

Resource extraction, defined here as the removal of minerals, metals or fossil fuels from the Earth's crust, is an integral component of historical and contemporary economic activity (Schrecker et al., 2018). As estimated in a United Nations Environment Programme report, global extraction of fossil fuels (by weight) increased 2.9%, metal ores 3.5% and non-metallic minerals 5.3% between 2000–2010 (Schandl et al., 2016). The same report documents a total of 2.4 billion tons of minerals and 5.6 billion tons of fossil fuels traded globally in 2010, compared to 370 million tons and 1.8 billion tons, respectively, in 1970. The wide range of activities comprising mining and oil & gas extraction, which differ in terms of variables such as operation size and specific substance extracted, complicate generalizations about resource extraction and its impacts (cf. Donoghue, 2004; San Sebastián and Hurtig, 2004). Nevertheless, a growing body of scholarship examines relationships between extractive industries and society, including applied inquiry to inform environmental assessments and other forms of resource extraction governance.

One prominent component of this growing literature focuses on health and well-being, reflecting known and probable pathways from resource extraction to serious population health impacts (London and Kisting, 2016; Schrecker et al., 2018). The health impacts of resource extraction involve toxic exposures and other occupational hazards, as well as economic, cultural, political and ecological interrelationships that increasingly fuel debates regarding benefit and risk trade-offs of resource development over time, especially in rural, remote and Indigenous communities (Goldenberg et al., 2010; San Sebastián and Hurtig, 2004). A combined view of the social, cultural and ecological determinants of health also draws attention to health inequities, which may be unnoticed in the 'cascade' of interrelated environment, community and health concerns arising as a result of resource development in the short, medium and long-term (Parkes et al., 2016).

Such scholarship on cumulative and social-ecological dimensions of health paints an increasingly complex picture. As numerous institutions and researchers have argued, however, the ways in which health

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impacts of resource extraction are studied and managed have not kept pace with this complexity (Mactaggart et al., 2016; Parkes et al., 2016; Peterson and Kosatsky, 2016). Gaps exist in terms of what is known about health outcomes associated with resource development, how pathways of impact are understood, and who is most affected. Masuda et al. (2008) argue that existing scholarship on environments and health disproportionately focuses on direct exposures to toxic substances, neglecting cumulative, inequity-laden and complex systemic pathways. Schrecker et al. (2018, p. 136) criticize "politically disembodied" scholarship on resource extraction and health, highlighting "case specific" studies that emphasize proximal determinants and neglect inequitable patterns of social determinants of health. Additional concerns are raised by studies of inappropriate resource extraction industry influences on the setting of research priorities and even on the conduct of research (Birn, 2014; Brisbois et al., 2016; Egilman, 2003; Kirsch, 2014; London and Kisting, 2016). Finally, resource extraction often occurs in settings marked by inequitable political economic power relationships, relationships that may be mirrored in patterns of research on related health impacts (Butchart, 1996; Butler, 2015). For example, the field of Health Impact Assessment (HIA), a prominent stream in current efforts to mitigate resource extraction's health impacts, has been characterized as insufficiently attentive to the historical and ongoing impacts of colonialism (Jones and Bradshaw, 2015). It is therefore important to assess the fit between existing knowledge, emerging understandings of complex social-ecological pathways to health impacts, and the urgent evidence and decision-making needs generated by burgeoning resource extraction activity around the world. The wide and complex range of pathways from resource extraction to health impacts described in recent scholarship additionally indicates a need to identify and rigorously apply a broad range of evidence types.

In this paper, therefore, we report on a scoping review conducted to answer the question, What is the scope of published literature that addresses the links between extraction of resources from the earth's crust (i.e. mining and oil & gas extraction), including subsequent transport of extracted materials, and health outcomes? We describe temporal and spatial patterns in overall research activity, topics and approaches, to inform future research in support of policy and practice for health equity. In particular, we describe an overwhelming preponderance of descriptive quantitative studies focused on direct occupational exposures to toxic substances, typically in high income and upper-middle income countries. Our findings show that studies of complex social-ecological pathways to health outcomes remain relatively scarce, as do intervention studies and research in low income and lower-middle income countries.

2. Materials and methods

Our overarching objective generated multiple sub-questions to understand how research was distributed, in terms of type of extractive activity (mining/oil & gas); affected population(s); study objectives (e.g. characterizing health impacts or describing various types of interventions); type of health impacts; general methodological approach; impact pathways studied (e.g. direct exposure to toxic substances vs. ecosystem change); and geographic (i.e. country) focus. We arrived at a scoping review methodology after considering other possible review approaches. Narrative reviews hold the potential for partial or idiosyncratic representations of existing knowledge, while systematic reviews to date have focused on narrow bodies of evidence in highly specific corners of the large literature on resource extraction and health. For example, one systematic review regarding health in relation to mountaintop removal coal mining in the Appalachian region of the US excluded review papers and other peer-reviewed sources not presenting new data (Boyles et al., 2017). We therefore chose a scoping review methodology for its ability to characterize the quantity, range and nature of existing research, and to identify gaps (Levac et al., 2010).

We applied the 6-step scoping review approach of Levac et al. (2010), building on the work of Arksey and O'Malley, 2005: [1] clarify the review's purpose and research question; [2] balance feasibility with breadth and comprehensiveness; [3] select studies using an iterative team approach; [4] extract data; [5] numeric summary and qualitative thematic analysis, reporting results and considering policy/practice/research implications of findings; and [6] consult with stakeholders to accomplish knowledge translation. Steps 1–3 and 6 involved ongoing discussions within the Health Impacts of Resource Extraction and Development (HIRED) project, a joint initiative of the University of Northern British Columbia and the Northern Health Authority of British Columbia. A health sciences librarian (TMF) provided guidance throughout the research process.

Our review was based on a search of peer-reviewed scholarship published in English from 1995 to October, 2015. The large volume of publications uncovered led to a multi-year inclusion/exclusion and data charting process, described below, and a focus on titles and abstracts rather than full-text documents. It was also not feasible to review either literature in languages other than English, or grey literature. Searches were carried out without geographic restrictions, using five databases (Medline OVIDSP, PsycInfo, CINAHL, LILACS, Web of Science ISI) and keywords for general and specific health and well-being outcomes, in combination with keywords for mining and oil & gas extraction or transport (list of keywords in Table 1; see also Supplementary File 1: Detailed Search Strategy).

After duplicates were removed, references were imported into the Zotero reference manager and inclusion and exclusion criteria were applied by the lead author, with questionable cases resolved and inclusion/exclusion criteria refined through discussion among the study's first author, research coordinator (JR) and broader project team. Publications were included if they were peer-reviewed journal articles, books or book sections. To be included, publications needed to have titles or abstracts indicating a focus on mining or oil & gas extraction or related transport of resources, in combination with discussion of a specific physiological/health/well-being/safety impact or aspect of

Table 1
Search terms.

Extractive Industries
Coal mine, Coal mining, Coal-bed methane, Development of natural gas, Development of shale gas, Development of unconventional oil and gas, Directional drilling, Drilling, Extraction, Extraction and processing industry, Fracking, Gas drilling, Gas rig, Hydraulic fracturing, Mining, Mining - open pit, Mining – opencast, Mining - closed pit, Mining – underground, Natural gas development, Natural gas exploration, Natural gas extraction, Offshore drilling, Oil and gas (oil & gas), Oil and gas drilling, Oil and gas extraction industry, Oil and gas industry, Oil and gas wells, Oil drilling, Oil extraction, Oil industry, Oil rig, Oilfield, Onshore drilling, Opencast mining, Petroleum industry, Pipeline, Shale, Shale gas exploitation, Shale gas extraction / development, Slick water stimulation, Unconventional gas extraction, Unconventional natural gas development
Health Outcomes/ Determinants / Fields of Study
Alcohol use, Alcohol Use Disorder/Alcoholism, Anxiety, Asthma, Bloodborne Pathogen infections, Cardiovascular disease, Chlamydia, Communicable Disease, COPD – Chronic Obstructive Pulmonary Disease, Crude Mortality Rate, Depression, Diabetes, Disability Adjusted Life Years, Drug use, Dyslipidemia, Environmental health, Family and Intimate Partner Violence, First Nations or Aboriginal or Indigenous Health, Gastroenteritis (GI infection), Gonorrhea, Happiness, Health Utility Index, Hepatitis B, Hepatitis C, HIV, Hypertension, Inactivity/Sedentary Behaviour, Infant Mortality Rate, Influenza, Injury, Ischemic Heart Disease, Invasive Meningococcal Disease, Invasive Pneumococcal Disease, Life satisfaction, Mastery/Self-esteem/Coherence, Measles, Mental Health, Metabolic Disorders, Mumps, Myocardial infarction, Norovirus, Other Infectious Diseases of interest, Pertussis, Poor diet, Potential Years of Life Lost, Premature Mortality rate, Public Health, Respiratory disease, Rubella, Rural health, Sexually Transmitted Infections, Stress, Stroke, Substance Use Disorder, Suicide Rate, Syphilis, Tobacco Use, Vaccine Preventable Disease, Well-being, Workplace injury – Musculoskeletal

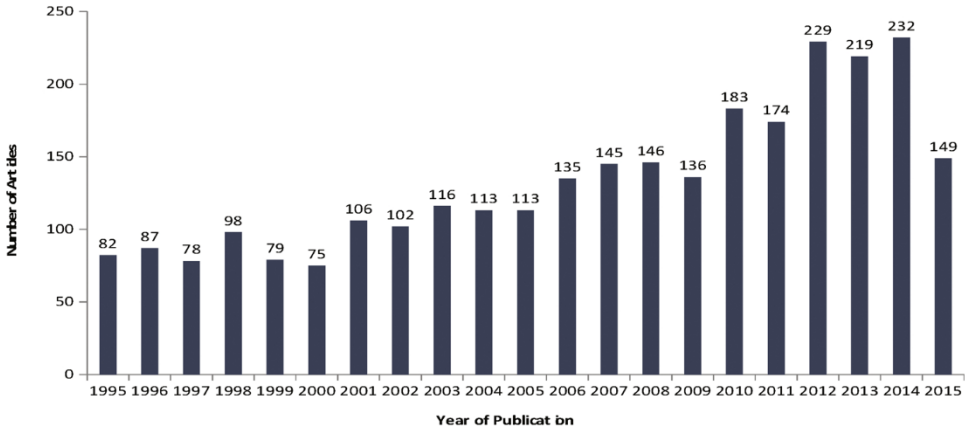


Fig. 1. Volume of resource extraction and health publications per year. Note that the figure for 2015 reflects only the period January-October of that year.

health-related services/interventions/diagnostic tests/advocacy/ policy/ litigation. Publications related to refining or processing of extracted resources were excluded as beyond the scope of the study.

The resulting sample of 2797 document titles/abstracts was divided among five research assistants (RAs). The RAs read through titles and abstracts and applied tags in Zotero using a charting or coding system developed through iterative dialogue among project partners to answer the research sub-questions described above. For each publication in the sample, tags were applied to identify the type of extractive activity described (i.e. mining, oil & gas, or both); affected population(s); study objectives (e.g. characterizing health impacts or describing various types of interventions); type of health impacts; basic methodological approach (quantitative/ qualitative/mixed/ historical); type of impact pathways examined (e.g. direct toxic exposures, social determinants or ecosystem change); and geographic focus (i.e. specific country/ies). Although the volume of publications in our sample and resource constraints precluded independent tagging of each title and abstract by two individuals, situations in which the appropriate tag to apply was at all unclear were resolved through discussion among the lead author, the research coordinator and the HIRED project partners.

With respect to geographic distribution of research, tagging by country names was consistent with the World Bank's June, 2017 list of economies (World Bank Data Help Desk, 2017). Assignment of country tags was typically based on the country where resource extraction activities took place, but could also refer to the home countries of migrant or offshore workers. Country tags were also applied to seven publications describing Canada's exports of asbestos, the sole example of a geographic focus based on impacts outside of the listed country. Tagging for 'Indigenous' affected populations was consistent with the United Nations Declaration on the Rights of Indigenous Peoples (United Nations, 2008). The affected population 'Indigenous' tag was applied to publications describing 'Indigenous', 'First Nations', 'Aboriginal' and 'First Nations' populations, excluding alternate usages of Indigenous-associated terms ('Indian' for residents of the country of India, for example). Ambiguous usages of Indigenous-related keywords were resolved though discussion between RAs and the research coordinator. Tagging of research approaches and topics was inclusive rather than limited to the central focus of the title and abstract. Not every reference received every category of tag, and some references received more than one tag per category if applicable. For example, a study of populations in two countries received two country tags. The tagging process corresponds to step 4 – extraction of data – in Levac et al.'s framework. Aligning with Stage 5, we then developed a numeric summary using Zotero's search functions and Microsoft Excel, and a qualitative thematic analysis of results by the lead author in collaboration with the authorship team.

Reporting of results in this article was guided by the PRISMA-ScR checklist for reporting of scoping reviews (Tricco et al., 2018). No publicly-available review protocol was published for this study; interested readers can contact the corresponding author for additional methodological information.

3. Results

3.1. Study selection

After duplicates were removed, a total of 18,320 publications were identified from database searches. Based on reading of titles and abstracts, a total of 15,523 documents were excluded, leaving a final sample of 2797 titles/abstracts (2772 journal articles, 24 book sections/ chapters and one book). A complete bibliography of the 2797 publications in our final sample is provided in Supplementary File 2: Bibliography of Included Sources.

3.2. Year of publication

The number of sources published per year generally increased over time (see Fig. 1). The lowest volume of sources published in a year was 75 in 2000, while the highest was 232 in 2014 (the figure for 2015, 149, is lower in part because searches were carried out at the end of October of that year).

3.3. Geographic focus

Eight countries accounted for 1350 publications (48.3% of the total volume of research uncovered): the United States (461 publications, or 16.5%), South Africa (212, or 7.8%), China (167, or 6.0%), Australia (147, or 5.3%), Canada (112, or 4.0%), Brazil (84, or 3.0%), Germany (83, or 3.0%) and the United Kingdom (82, or 3.0%). While geographic tagging typically identified countries that were a location of extraction activities or source of migrant or offshore labor, the total for Canada also includes seven publications focused on health impacts of Canadian asbestos exports around the world. Figures for some countries also reflect exposures by military personnel to burning oil wells during the Persian Gulf War (6 publications from the United States, 2 from the United Kingdom and 1 each from Australia and Canada).

Conversely, 10 or fewer publications were found for 82 different countries. Some countries only registered at all because of multi-country review papers, such as a paper on arsenic exposure in Latin America that accounted for the sole representation in the final sample of Cuba, El Salvador, Honduras and Uruguay. In other cases, a single mine or research program appeared to dominate research focused on a particular country. For example, five of six Guatemala-focused publications described health consequences of the infamous Marlin gold mine (the sixth being the aforementioned arsenic review). The eight countries with the highest representation in the final sample are all

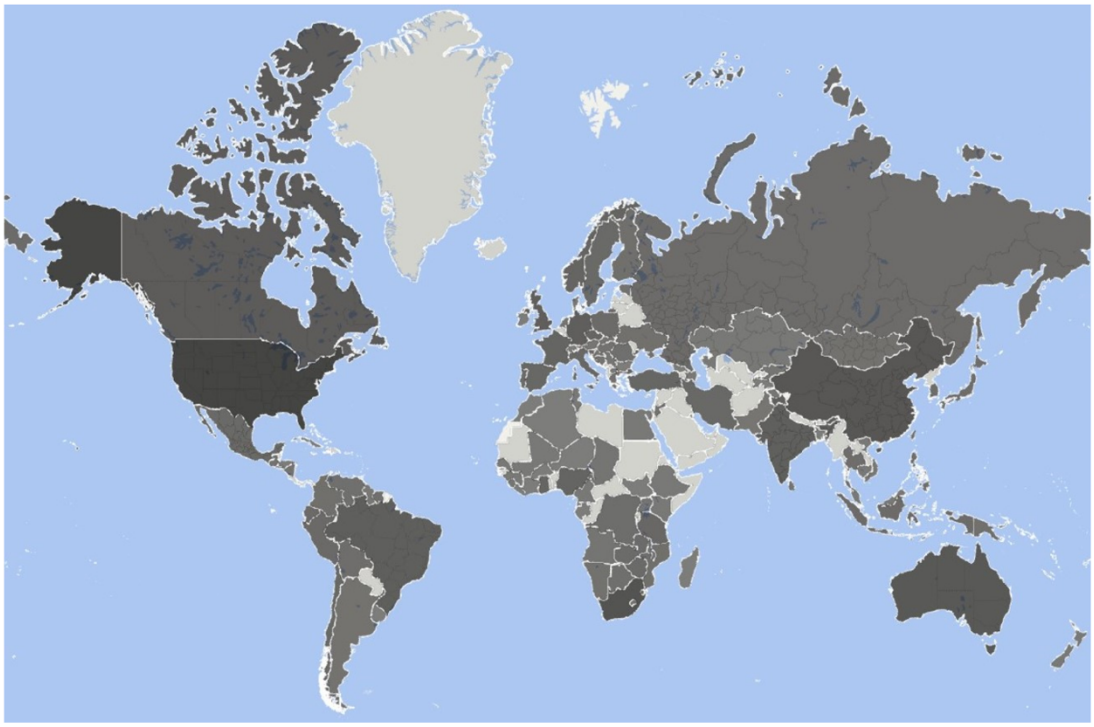


Fig. 2. Geographic distribution of research on resource extraction and health. The volume of research is represented as a gradient from countries with no representation in the sample (lightest), through to the United States, with 461 publications in the sample (darkest).

either 'high income' countries (HICs) or 'upper-middle income' countries (UMICs) according to the World Bank's June, 2017 classification of country economies. Indeed, a total of 1172 publications (41.9% of the final sample) focused on HICs, 669 (23.9%) on UMICs, 275 (9.8%) on 'lower-middle income' countries (LMICs) and only 75 (2.7%) on 'low income' countries (LICs).

Eighty-two publications were tagged with multiple country names, for example comparative studies, multi-country cohorts and studies of migrant labor. Eleven focused on migrants working in South African mines from surrounding countries such as Mozambique, Lesotho, Swaziland, Botswana and Zimbabwe. Small numbers of studies named geographic areas rather than, or in addition to, specific countries, for example 'developing countries' (1 publication), bodies of water where offshore oil & gas activities take place (e.g. the North Sea, with 7 publications), and multi-country regions such as 'Southern Africa' (4 publications), 'the Amazon' (1 publication) and 'Lake Victoria' (1 publication). In contrast to the majority of publications that referenced at least one specific country or an identifiable geographic region, 22.3% (624) provided no geographic identifying information in their titles and abstracts. Fig. 2 maps the volume of research across countries of the world.

3.4. Sector/type of extractive industry

A majority of publications dealt with one or more varieties of mining (2395, or 85.6%), while 15.0% (420) described oil & gas extraction activities and 18 described both mining and oil & gas, or 'resource extraction' more generally. Of the sources tagged with 'mining', 134 referred to small-scale or artisanal gold mining. Four studies describing small-scale gold mining were linked with HICs: two in Chile, and two in French Guiana that were tagged with 'France'. UMICs were the site of 53 studies on small-scale gold mining, LMICs of 43 and LICs 25.

3.5. Affected population(s)

Of publications that mentioned a specific population affected by mining or oil & gas activities, 67.9% (898) focused on workers. Impacts on communities adjacent to resource extraction activities were described in 22.3% (624). When sex/gender was explicitly mentioned, more than twice as many studies (239) were about impacts on men than about impacts on women (99). Other affected populations included children (130), migrants (57), sex workers (18) and seniors (5) (see Fig. 3 for a summary of the distribution of publications by affected population). A total of 67 sources focused on Indigenous populations. Of the publications with Indigenous populations affected by resource extraction, 34 dealt with HICs, 19 UMICs, 10 LMICs and none with LICs.

3.6. Study objectives

Most publications (2409, or 86.1%) had study objectives that included characterizing one or more health impacts in relation to

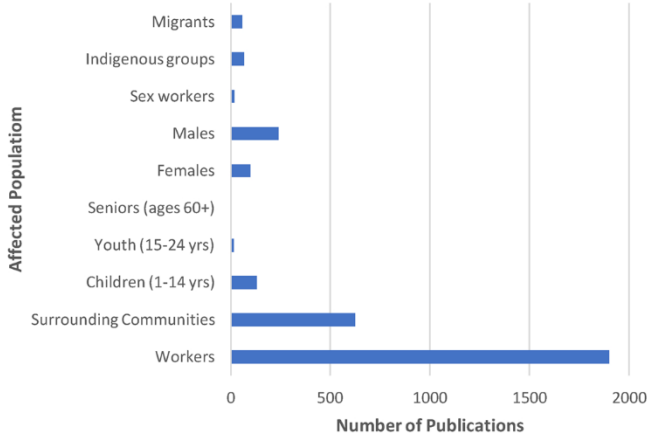


Fig. 3. Affected populations in research on resource extraction and health.

resource extraction. Other studies (11.4% of the total) focused on occupational health & safety interventions (198) or interventions such as regulations/policies (64) or health promotion programs (58). Comparatively few studies described social movement responses to resource extraction's health impacts (33) or controversies or advocacy initiatives involving scientists (63). A total of 16 publications discussed the practice of 'health impact assessment', of which 9 were tagged with the objective of characterizing health impacts, five described regulatory/ policy interventions and two described controversies/ advocacy. Of these 16 HIA-focused publications, 3 received an HIC tag, 1 a UMIC tag, 5 a LMIC tag, 4 a LIC tag, and 5 did not feature a specific country.

3.7. Type of health impacts

The most frequently studied health impacts were respiratory issues (607 publications), cancer (493), poisonings or blood disorders (289) and acute injuries (218). Chronic diseases and chronic injuries were the subject of 102 and 108 publications, respectively. The 256 sources related to infectious disease were divided between sexually transmitted infections (133) and other infectious diseases (158), with some publications discussing both categories. Mental health or psychosocial impacts were featured in 124 sources and general well-being or quality of life considerations in 54. The search surfaced a single study focused on mental health or psychosocial impacts in an LIC (Zimbabwe) and 13 in LMICs, in comparison to 29 with this focus in UMICs and 53 in HICs. Fig. 4 illustrates the distribution of health outcomes studied.

3.8. Methodological approach

According to a rudimentary methodological characterization, most sources (2350, or 84.0%) employed 'quantitative' methods (epidemiologic/biostatistical but also in environmental science and other relevant fields). A much smaller number (132, or 4.7%) employed methods explicitly described as 'qualitative', or identified by the research team as focusing on interpretations of human experience (ethnography or narrative methods, for example). A small number employed both quantitative and qualitative (or 'mixed') methods (84). A similar number (89) employed explicitly 'historical' methods or described social events in recognizable periods in the past, such as studies of labor movements in early 20th-century Great Britain. In some cases (164), no discernible methodology was evident from the title or abstract.

3.9. Type of impact pathways examined

The pathways to health outcomes explored across our sources primarily focused on direct exposures to toxic chemicals, radiation, vibration, or noise (1632 publications or 58.3%). Notably, 1005 of these sources focused on noxious exposures dealt with the health of workers, comprising 35.9% of the total sample. The two categories of health outcome that were most frequently studied in relation to noxious exposures were respiratory impacts (494 publications) and cancer (435), with studies of these health impacts due to such exposures accounting for 33.2% of the entire body of research on resource extraction and health uncovered in this review. Numerous studies also focused on workplace accidents (474), or simply being in a specific occupation as a health risk (272). An additional body of studies (220) focused on behaviours as determinants of health, with an unusual pattern observed in terms of geographic distribution. In contrast to the overall sample, in which 41.9% of publications focused on HICs, only 20.0% of publications involving behavioural pathways to health outcomes were in HICs. Fully 51.8% of sources involving behavioural determinants of health were focused on UMICs, especially South Africa with 36.4%.

A total of 68 publications described the health impacts of specific disasters, of which 58.8% focused on HICs and none at all on LICs. Relatively few studies focused on pathways involving ecosystem changes (312, or 11.2%) or social determinants (105, or 3.8%). Of studies detailing ecosystem change pathways from resource extraction to health, 13 focused on LICs, 61 on LMICs, 111 on UMICs and 108 on HICs. Table 2 shows publications per impact pathway, cross-referenced with specific health outcomes studied, affected populations, methodological approaches and geographic foci.

4. Discussion

4.1. Main findings

The purpose of this scoping review was to map peer-reviewed literature on links between resource extraction from the earth's crust (i.e. mining and oil & gas) and health outcomes. Key findings include prominent emphases on mining, rather than oil & gas extraction; on workers; on high income and upper-middle income countries; on studies characterizing health impacts rather than reporting on interventions and responses; on quantitative methods; and on relatively direct pathways to health outcomes from noxious exposures. Important emerging themes in scholarship on resource extraction and health, such as mental health and well-being, and ecological and social

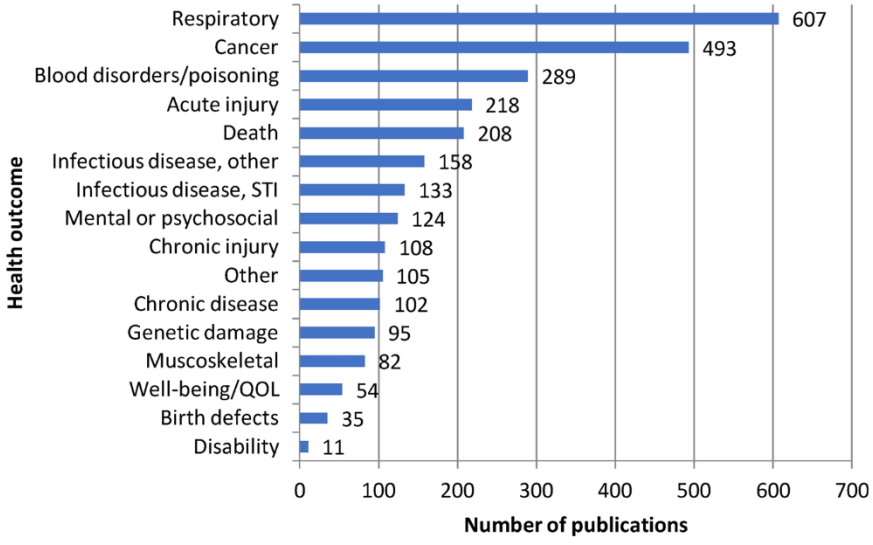


Fig. 4. Specific health outcomes in research on resource extraction and health.

Table 2
Health impacts, geographic focus, affected population and methodological approach by pathways to health outcomes.

Pathway to health impacts (# publications) →	Toxic exposures (1632)	Behavioural or social (220)	Ecosystem change (312)	Social determinant (105)	Workplace condition (474)	Occupation name (272)	Disaster (68)
Health impact (# publications)	**Number of publications (% of total in impact pathway)**						
Mental / psycho-social (124)	13 (0.8)	24 (10.9)	6 (1.9)	19 (18.1)	49 (10.3)	11 (4.0)	19 (27.9)
Respiratory (607)	494 (30.3)	14 (6.4)	19 (6.1)	5 (4.8)	33 (7.0)	72 (26.5)	3 (4.4)
Cancer (493)	435 (26.7)	6 (2.7)	29 (9.3)	6 (5.7)	11 (2.3)	55 (20.2)	2 (2.9)
Musculoskeletal (82)	10 (0.6)	4 (1.8)	0 (0)	1 (1.0)	42 (8.9)	18 (6.6)	0 (0)
Infectious disease – STI (133)	15 (0.9)	94 (42.7)	1 (0.3)	17 (16.2)	5 (1.1)	18 (6.6)	0 (0)
Infectious disease – other (158)	44 (2.7)	52 (23.6)	27 (8.7)	6 (5.7)	17 (3.6)	27 (9.9)	0 (0)
Genetic damage (95)	84 (5.1)	1 (0.5)	7 (2.2)	1 (1.0)	0 (0)	8 (2.9)	2 (2.9)
Acute injury / accident (218)	12 (0.7)	16 (7.3)	1 (0.3)	4 (3.8)	132 (27.8)	44 (16.2)	14 (20.6)
Chronic injury (108)	20 (1.2)	8 (3.6)	0 (0)	2 (1.9)	66 (13.9)	15 (5.5)	0 (0)
Disability (11)	3 (0.2)	0 (0)	0 (0)	0 (0)	6 (1.3)	1 (0.4)	0 (0)
Death (208)	82 (5.0)	8 (3.6)	3 (1.0)	6 (5.7)	56 (11.8)	53 (19.5)	16 (23.5)
Well-being (54)	3 (0.2)	12 (5.5)	7 (2.2)	18 (17.1)	12 (2.5)	4 (1.5)	4 (5.9)
Birth defects / pregnancy (35)	28 (1.7)	1 (0.5)	4 (1.3)	2 (1.9)	1 (0.2)	0 (0)	0 (0)
Other (105)	59 (3.6)	5 (2.3)	9 (2.9)	3 (2.9)	23 (4.9)	14 (5.1)	1 (1.5)
Chronic disease (102)	70 (4.3)	8 (3.6)	9 (2.9)	3 (2.9)	10 (2.1)	10 (3.7)	2 (2.9)
Poisoning / blood disorders (289)	285 (17.5)	5 (2.3)	137 (43.9)	11 (10.5)	4 (0.8)	2 (0.7)	2 (2.9)
Geographic focus (# publications)	**Number of publications (% of total in impact pathway)**						
Lower income country (75)	28 (1.7)	18 (8.2)	13 (4.2)	8 (7.6)	11 (2.3)	4 (1.5)	0 (0)
Lower middle income country (275)	140 (8.6)	27 (12.3)	61 (19.6)	23 (21.9)	40 (8.4)	25 (9.2)	5 (7.4)
Upper middle income country (669)	383 (23.5)	114 (51.8)	111 (35.6)	26 (24.8)	80 (16.9)	63 (23.2)	6 (8.8)
High income country (1172)	734 (45.0)	44 (20.0)	108 (34.6)	43 (41.0)	187 (39.5)	123 (45.2)	40 (58.8)
No geographic identifier (624)	358 (21.9)	23 (10.5)	23 (7.4)	8 (7.6)	154 (32.5)	56 (20.6)	15 (22.1)
Affected population (#publications)	**Number of publications (% of total in impact pathway)**						
Workers (1898)	1005 (61.6)	164 (74.5)	31 (9.9)	28 (26.7)	450 (94.9)	259 (95.2)	31 (45.6)
Surrounding communities (624)	488 (29.9)	41 (18.6)	217 (69.6)	42 (40.0)	10 (2.1)	6 (2.2)	18 (26.5)
Indigenous group (67)	49 (3.0)	7 (3.2)	27 (8.7)	16 (15.2)o	1 (0.2)	2 (0.7)	1 (1.5)
Migrants (57)	10 (0.6)	25 (11.4)	0 (0)	9 (8.6)	8 (1.7)	7 (2.6)	0 (0)
Sex workers (18)	0 (0)	14 (6.4)	0 (0)	3 (2.9)	0 (0)	1 (0.4)	0 (0)
Children (130)	120 (7.4)	8 (3.6)	44 (14.1)	11 (10.5)	3 (0.6)	1 (0.4)	1 (1.5)
Youth (15)	8 (0.5)	4 (1.8(	1 (0.3)	2 (1.9)	1 (0.2)	0 (0)	1 (1.5)
Males (239)	144 (8.8)	27 (12.3)	7 (2.2)	7 (6.7)	34 (7.2)	41 (15.1)	4 (5.9)
Females (99)	63 (3.9)	12 (5.5)	13 (4.2)	20 (19.0)	4 (0.8)	5 (1.8)	2 (2.9)
Seniors (5)	3 (0.2)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0.7)	0 (0)
Methodological approach	**Number of publications by methodological approach (% of publications in impact pathway)**						
Quantitative (2350)	1483 (90.9)	147 (66.8)	271 (86.9)	56 (53.3)	400 (84.4)	249 (91.5)	42 (61.8)
Qualitative (132)	35 (2.1)	39 (17.7)	11 (3.5)	33 (31.4)	18 (3.8)	4 (1.5)	5 (7.4)
Mixed methods (84)	32 (2.0)	23 (10.5)	11 (3.5)	5 (4.8)	22 (4.6)	0 (0)	6 (8.8)
Historical (89)	46 (2.8)	6 (2.7)	7 (2.2)	2 (1.9)	7 (1.5)	11 (4.0)	5 (7.4)
No identifiable methodology (164)	45 (2.8)	9 (4.1)	13 (4.2)	9 (8.6)	30 (6.3)	13 (4.8)	10 (14.7)

determinants, were found to be relatively underrepresented, especially in LICs and LMICs.

4.2. Limitations

A main limitation of our analysis is its focus on literature published up to late-2015, thus missing an important time period (2016–2018) that has likely seen an increasing volume of relevant scholarship, and greater attention to complex ecosystemic, social determinants and cumulative impacts pathways. This limitation is due in part to the scope of the task of characterizing scholarship on resource extraction and health, which generated large numbers of references to screen and characterize. Another obvious limitation is our focus on only English-language and peer-reviewed scholarship. Many occupational health studies in the mining industry, for example, are presented at conferences and not available through database searches of peer-reviewed literature (Donoghue, 2004). We also did not differentiate within two main types of resource extraction (mining and oil & gas development), beyond identifying the relatively small number of studies on small-scale (artisanal) gold mining. The scale of mining operations (often linked to the substance being extracted) and type (open-pit, etc.) affects both occupational and environmental health risks, and the feasibility of related health research (Donoghue, 2004; Stephens and Ahern, 2002).

A further limitation to this study is our focus on titles and abstracts, which limited our depth of engagement with the content of uncovered scholarship. While necessitated by the large volume of research we

encountered, this choice prevented us from carrying out detailed assessments of study design or rigor. Our scoping review thus suggests that a full systematic review – or likely several – could more comprehensively unpack patterns and possible biases in the types of research that are funded, conducted, and ultimately published. Such patterns might relate to expectations surrounding traditional methods of biomedical research, discursive and corporate influences on the framing of research questions, and the challenges of matching research design to the complexity of cumulative determinants of health impacts from resource development (Parkes et al., 2016). Finally, our search terms were refined in collaboration with our main knowledge user, a public health department located in a global North setting, and therefore do not uniformly represent all pathways from resource extraction to health worldwide. The search did yield numerous papers on global South-specific impacts of resource extraction (e.g. malaria and other infectious diseases linked to small-scale gold mining), however, suggesting that these were still largely captured by the search strategy. Future reviews could improve on this search strategy through a more comprehensive global approach to keyword selection.

4.3. Explanation and implications of findings

While we are not aware of any comparable global analyses against which to compare our results, several key themes merit further discussion, bearing in mind the need to carefully extrapolate results from 2015 to the present. Of note is the fact that, while fossil fuels overshadow minerals as the dominant commodity traded globally in terms of both economic value and tons extracted (Schandl et al., 2016), only 420 publications focused on oil & gas activities, in comparison to 2395 focused on mining and 18 focused on resource extraction more generally (though the figure for mining includes coal, a fossil fuel). This difference could be partially explained by an International Labour Organization, 2018 estimate that the petroleum industry currently employs almost six million people worldwide, in comparison to the approximately 25 M workers employed in mining in a 1993 ILO report (International Labour Office, 1993). The fact that only 18 publications focused on resource extraction more generally, moreover, suggests that scholarship on resource extraction and health remains segmented by sector (i.e. focused on mining OR oil & gas).

With respect to pathways of impact, the preponderance of studies focused on direct exposures to toxic chemicals, noise, vibration or radiation (58.3% of sources) is noteworthy. Given the prominence of occupational health studies in our sample, this emphasis can be explained at least in part by the historical development of the field of industrial hygiene (a main precursor of today's occupational and environmental health sciences). Emphasis on exposure to specific chemicals, amenable to toxicological study and divorced from the messiness of workplace politics and environmental complexity, reflects the ongoing effects of an early-20th-century 'compromise' between industrial hygiene and the industries it relied on for development as an applied academic field (Nash, 2006; Sellers, 1997). The durable nature of such patterns in occupational and environmental health research suggests that the focus on direct noxious exposures observed to late-2015 has likely continued, albeit perhaps mitigated by increased attention to complexity and equity in recent scholarship.

Indeed, the importance of understanding complex interacting social-ecological pathways to health outcomes is underscored by emerging scholarship on 'cumulative impacts', which refers to relationships of new development activities in particular places to preexisting impacts of historical land-use decisions, and multiple overlapping land uses (Gillingham et al., 2016). A cumulative perspective on the health impacts of resource development recognizes the environment as a source of hazardous exposures, but also notes that ecosystems and biodiversity, the living systems on which life and health depend, contribute to the determinants of health through livelihoods, lifestyles, culture and identity (Horwitz and Kretsch, 2015; Parkes and Horwitz, 2016). Within 'cascades' of interacting social and ecological pathways to health outcomes, inequities may arise as a consequence of livelihood pursuits, whether among workers, or in families of workers (Kinnear et al., 2013; Northern Health, 2012); lived experiences and local concerns (Lindsay, 2016; Mitchell-Foster and Gislason, 2016; Office of the Chief Medical Officer of Health (OCMOH), 2012; physical or sexual violence involving extractive company supporters or security personnel in the face of community resistance to resource extraction (Butler, 2015; Gordon and Webber, 2016; London and Kisting, 2016; Schrecker et al., 2018); or the mental health and well-being implications of changes to local environments and communities (Albrecht et al., 2007; Cunsolo Willox et al., 2013; Harder, 2016). Such impacts are particularly pertinent in Indigenous communities where health-promoting cultural and material connections to land are especially threatened by resource extraction, often in the context of political marginalization and related historical trauma (Richmond, 2015). The relatively small amount of research focused on nominally Indigenous populations (67 documents, or 2.4% of the final sample) thus suggests a problematic pattern of neglect.

The focus on descriptive studies we observed is also consistent with longstanding calls in occupational health and safety research for more intervention studies to reduce, rather than merely describe, occupational health impacts (Goldenhar et al., 2001). As a US-based expert panel observed 17 years ago, however, intervention research in occupational health and safety has been chronically underfunded, and is complicated by the diversity of possible interventions and the complex and changing circumstances affecting their outcomes (Goldenhar et al., 2001). The panel also described a lack of research on policy interventions, consistent with the small number of documents in our sample (64) describing policy or regulatory interventions. One reason for this gap is suggested by the panel's observation that evaluation of policy interventions is especially difficult, typically involving large studies, attention to unruly real-world influences on intervention design, and possible ethical obstacles. Occupational health researchers and related institutions have attempted to address such research gaps through priority-setting exercises carried out by the US National Institutes of Occupational Safety and Health (NIOSH) and the World Health Organization's Collaborating Centres in Occupational Health, as well as 'Delphi processes' involving interviews and surveys with experts from academia, industry and government in various countries (Iavicoli et al., 2005). However, as the authors of one such priority-setting study observe, experts "have their own interests (in more than one meaning of the word)" (van der Beek et al., 1997, p. 508). We interpret this statement to refer to the possibility of experts' excessive attachment to their own specialized research domains to the detriment of overall population health objectives, as well as possible financial conflicts of interest (industry ties, for example) among many occupational health and safety experts. Unfortunately, examining funding sources of publications included in our sample was beyond the scope of the present review.

More generally, thoroughly explaining patterns of research would also require examining author affiliations and funding sources, for example of global health studies carried out by researchers from the global North in countries of the global South (or for 'South-South' collaborations). Patterns of global health research are also influenced by a number of forces including dominant biomedical narratives and corporate actors and their associated large foundations (Birn, 2014; Leach and Scoones, 2013; McCoy et al., 2009). Indeed, research on mining and health can be generated, funded or influenced by mining companies to avoid community or regulatory resistance to mining developments (Egilman, 2003; Kirsch, 2014).

The geographic distribution of research is also noteworthy for several reasons. The 22.3% of publications listing no geographic identifiers is consistent with the ideal of scientific knowledge as universal and applicable anywhere in the world (Watson-Verran and Turnbull, 1995). The relative emphasis on HICs and UMICs (1841 publications, in comparison to 350 for LMICs and LICs), moreover, is generally consistent with the '10/90 gap', or the estimate that 90% of the world's

health research resources target the health problems of the world's wealthiest 10% (Davey, 2004). It also echoes Stephens and Ahern's (2002) 'rapid review' of research on mining and health, which found a preponderance of studies focused on the United States, Australia, Canada and Europe (although the presence of China, Brazil and South Africa in the top eight sites of research in our study is noteworthy). With specific respect to HIA, Erlanger et al. (2008) describe the so-called '6/94 gap', in which only 6% of published HIAs targeted the 'developing world'. In our results, however, 9 of 16 studies mentioning 'health impact assessment' were tagged as LICs or LMICs, while only 4 were tagged as HICs or UMICs. The decade that passed between Erlanger et al.'s study and our own may help to explain this difference; in addition, our findings reflect only HIAs connected to resource extraction.

Further explaining geographic patterns would involve tracing trends in resource extraction activity, determining the labor-intensiveness and riskiness of each type, and examining factors influencing where in the world research and HIAs typically happen. In addition, the fact that we included only English-language literature may help explain the relative dearth of research observed in LICs and LMICs. Patterns of resource extraction in such countries reflect geopolitical developments such as economic restructuring in the post-Cold-War period enforced by conditional loans to highly-indebted countries by international financial institutions (Bebbington and Bury, 2013). Such reforms typically increased access to mineral and petroleum resources for transnational corporations, thereby increasing the volume of resource extraction activity available to be represented in our sample – and, according to many communities, researchers and activists, generating substantial health harms through environmental and human rights violations (Butler, 2015; Kirsch, 2014; Schrecker et al., 2018).

It is possible that resource extraction disasters attract proportionately more research attention than the health implications of 'everyday' mining and oil & gas activities (we are grateful to an anonymous reviewer for this observation). We found 68 studies of resource extraction disasters, or 2.4% of all reviewed documents, suggesting that routine resource extraction activities do in fact account for the bulk of related health scholarship. The complete absence of studies addressing health impacts of resource extraction disasters in LICs is especially problematic in light of burgeoning resource extraction activity in such countries. To illustrate reasons for and implications of this gap, it is worth examining the 1995 Omai gold mine tailings pond breach in Guyana – then the 2nd-poorest country in the western hemisphere – which sent an estimated 1.2 billion litres of cyanide slurry into the Essequibo River watershed (Bulkan and Palmer, 2016). While effects on the biodiverse watershed and its Indigenous and peasant communities were described anecdotally as enormous and devastating, a lack of research capacity and political will to investigate impacts limited documentation of health consequences (Roopnarine, 2002). Thus a major disaster occurring at the beginning of the time period we examined, at what was then South America's largest gold mine, is not represented in our final sample.

4.4. Political economic drivers of observed patterns

With respect to the causes of such understudied disasters, establishment of the Canadian-owned Omai mine was made possible by the forced liberalization of Guyana's economy, including rewriting of its mining code, imposed by international lenders and led by Canada's development sector (Black and McKenna, 1995; Canterbury, 2016). The Omai example therefore illustrates how the political economic drivers of resource extraction (cf. Schrecker et al., 2018) are likely to create future health impacts in precisely the places most neglected by researchers. In that the health impacts of this disaster were shaped by decisions taken in another country, moreover, it also illustrates the complexity of explaining and interpreting the geographic distribution of research on resource extraction and health. Canada was the 5th most common country focus in our sample. 'Canadian' mining companies raised a world-leading $8.9 (US) in equity financing for mining and mineral exploration in 2014, but this figure obscures the fact that many such firms are based in Canada solely to take advantage of a hospitable taxation and regulatory climate, with investors, corporate decision-making, mining activities and related health impacts (and health research) occurring elsewhere (cf. Gordon and Webber, 2016; Heidrich, 2016). Future efforts to explain patterns of research on resource extraction and health should therefore be attentive to complex cross-border flows of investment in the extractive sector.

Additional equity implications of geographic patterns of research are illustrated by the 212 publications focused on South Africa (second only to the United States), including 11 sources dealing with migrant workers from neighboring countries working in South African mines. Most obviously, South Africa has a relatively well-developed university system, and issues of national concern such as the spread of HIV among mine worker populations have fostered intense research interest (Corno and de Walque, 2012). Indeed, the unusual concentration of research on behavioural pathways to health outcomes in UMICs was driven by 44 studies on sexually-transmitted infections (i.e. HIV) in South Africa, the same number of behavioural pathway studies carried out on all health conditions in all HICs. Thus domestic and migrant mining workers, sex workers and mining communities in South Africa have contributed as much to knowledge on behaviours and health in resource extraction as has the entire population of HICs.

Historical analyses, in addition, have shown that the explosion of mining activity in colonial and apartheid South Africa was fueled by systematic efforts to dispossess black South Africans of their land and make them available as a compliant labor force, eventually confined to apartheid-era townships in close proximity to industrial sites such as mines (Butchart, 1996). Butchart's analysis traces the ways in which early-20th-century 'mining medicine' in South Africa constructed racist portrayals of the body of 'the African miner' (both domestic and migrant) while simultaneously building health research capacity related to mining and helping provide a docile labor force to earn profits for white South African and foreign mining interests. Patterns of resource extraction in Latin America have also been historically shaped by imperialist interventions of European and later North American powers, in ways that simultaneously dispossessed Indigenous peoples and peasant communities of their lands, generated health-damaging patterns of environmental contamination, and made displaced communities available to participate in mining labor – and, eventually, in health studies related to mining (Galeano, 1997; Gordon and Webber, 2016).These examples illustrate the need to pay attention to historical and ongoing political economic inequities in explaining both the distribution of resource extraction, and the distribution of research on its health impacts. This point is also underscored by Canada's development into a global mining powerhouse through historical appropriation of Indigenous lands, and subsequent widespread funding of Canadian universities and researchers by leading mining firms (Brisbois et al., 2016; Butler, 2015; Tannock, 2010).

5. Conclusions

Assuming the patterns described above are at least partially reflected in scholarship in the years since 2015, it appears that research priorities on resource extraction and health should be reoriented to more thoroughly explore implications of oil & gas extraction, as well as impacts of resource extraction on populations other than workers. Complex and cumulative socio-ecological dynamics, pathways to health outcomes other than direct toxic exposures, qualitative and mixed methods, and neglected topics such as mental health and well-being all appear relatively under-researched. Such gaps appear especially problematic in light of the growing body of research on cumulative impacts involving complex ecosystem and social determinants pathways (Gillingham et al., 2016; Kinnear et al., 2013). The need to

acknowledge complex social and ecological pathways to health outcomes is a central theme of a number of emerging and established fields, from ecohealth and one health to planetary health and political ecology of health. Such fields often advocate transdisciplinary approaches, participatory techniques to promote equity and elicit local knowledge, and policy-engaged or applied research (Buse et al., 2018). This growing body of scholarship could provide guidance to help overcome research gaps uncovered in our review, and inform applied research for health equity and sustainability.

Given the fact that resource extraction now occurs in increasingly-remote parts of the world often inhabited by Indigenous and other marginalized communities, moreover, the relative dearth of studies on Indigenous populations and in LMICs and LICs is revealing (cf. People's Health Movement, 2015). Research into determinants of research priorities such as corporate power, disciplinary identity and discursive effects of major political economic inequities could provide support to researchers seeking to promote health equity in relation to resource extraction. As the South African and Canadian examples show, however, problematic influences on the distribution of research reflect deep and inequitable power dynamics influencing patterns of resource extraction and vulnerability to related health impacts around the world (cf. Schrecker et al., 2018). Merely correcting perceived imbalances in research on health in relation to resource extraction may therefore not be the only, or even the primary, appropriate response. Political engagement and community empowerment, which are far less 'productive' in terms of research outputs than the descriptive studies that dominate existing scholarship uncovered in this review, should be prioritized as strategies to mitigate adverse health impacts of resource extraction.

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Declarations of interest

None.

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