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Chronic environmental contamination: A systematic review of psychological health consequences

Harrison J. Schmitt[a,*], **Eric E. Calloway**[b], **Daniel Sullivan**[a], **Whitney H. Clausen**[b], **Pamela G. Tucker**[c], **Jamie Rayman**[c], **Ben Gerhardstein**[c]

[a]Department of Psychology, University of Arizona, 1503 E University Blvd. Building 68, Tucson, AZ 85721, USA

[b]Gretchen Swanson Center for Nutrition, 8401 W Dodge Rd, Omaha, NE 68114, USA

[c]Agency for Toxic Substances and Disease Registry, 1600 Clifton Road, Atlanta, GA 30329, USA

Abstract

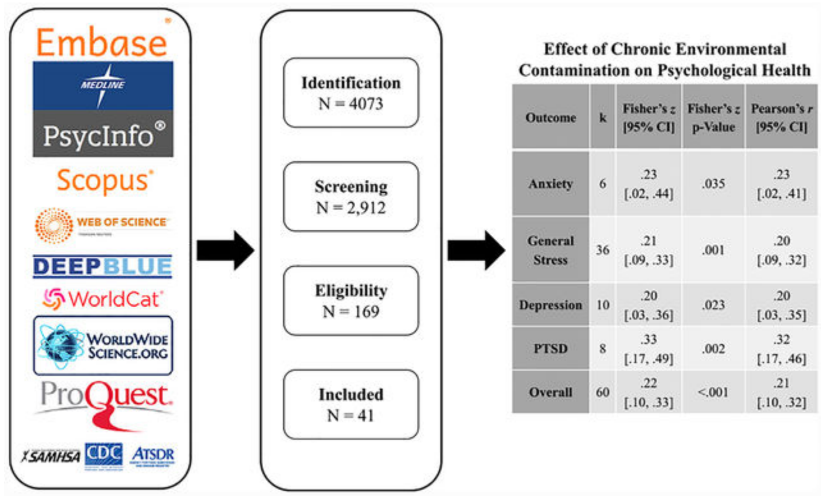
We sought to undertake a systematic review to assess the current research and to provide a platform for future research on the psychological health impact of chronic environmental contamination (CEC). CEC is the experience of living in an area where hazardous substances are known or perceived to be present in air, water, or soil at elevated levels for a prolonged and unknown period of time. We employed a systematic review approach to assess the psychological health impact of CEC in literature from 1995 to 2019, and conducted a meta-analysis of available findings (k = 60, $N = 25{,}858$) on the impact of CEC on anxiety, general stress, depression, and PTSD. We also present a narrative synthesis of findings that suggest risk factors for the experience of psychological health impacts in the wake of CEC. Likely factors increasing risk for elevated psychological health impact from CEC experience are institutional delegitimization of community concerns and the real or perceived presence of health effects from CEC. The meta-analyses observed small-to-medium effects of experiencing CEC on anxiety, general stress, depression, and PTSD. However, there was also evident risk of bias in the data. Our review suggests that psychological health in the context of CEC is an important potential public health burden and a key area for future improved research.

GRAPHICAL ABSTRACT

[*]Corresponding author. hschmitt@email.arizona.edu (H.J. Schmitt).

Declaration of competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data
Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.145025.



Outcome	k	Fisher's z [95% CI]	Fisher's z p-Value	Pearson's r [95% CI]
Anxiety	6	.23 [.02, .44]	.035	.23 [.02, .41]
General Stress	36	.21 [.09, .33]	.001	.20 [.09, .32]
Depression	10	.20 [.03, .36]	.023	.20 [.03, .35]
PTSD	8	.33 [.17, .49]	.002	.32 [.17, .46]
Overall	60	.22 [.10, .33]	<.001	.21 [.10, .32]

Keywords

Chronic environmental contamination; Mental health; Stress

1. Introduction

Chronic environmental contamination (CEC) is the experience of living in an area where hazardous substances are known or perceived to persist over time in air, water, or soil at elevated levels. This contamination may be chemical or radiological, and the result of prior or current industrial processes or a technological accident (Couch and Coles, 2011). CEC may pose toxicological health risks if someone is exposed. The experience of long-term exposure to environmental contamination can also be psychologically stressful for some members of an affected community (Baum and Flemming, 1993; Havenaar and Van den Brink, 1997; Tucker, 1998). Chronic stress can have a variety of deleterious physical health effects such as immune suppression or dysregulation (Dhabhar, 2011), risk of obesity, Type II diabetes, atherosclerosis, and early cognitive decline (McEwen, 2008). Stress and its associated health effects may interact with toxicant exposure to negatively impact already vulnerable populations (Segal et al., 2015).

Addressing psychological health impacts in communities living with CEC is therefore important for improving their health (Hoover et al., 2015). We define psychological health impacts broadly in this review, so as to encompass the wide range of psychological health variables assessed across this literature. Psychological health impacts can be thought of as the various emotional, psychological, and behavioral effects that experiencing CEC may have on an individual or community that can strain their ability to cope (Gerhardstein et al., 2019). It is crucial to consider both individual psychological effects as well as psychosocial effects – community-level factors through which broader structural forces impact residents. These issues underscore the importance of the central question of this review: What is the impact of experiencing CEC on psychological health? As part of a project initiated by the Agency for Toxic Substances and Disease Registry (ATSDR), we undertook a systematic review assessing the psychological health impact of chronic contamination experience.

The existing literature that has assessed the psychological health impact of CEC is limited due to the many research barriers inherent to CEC events. The systematic review and meta-analysis presented here serve to synthesize the existing literature in order to assess the extent of the psychological health impact of CEC, to understand the limitations of the literature and the barriers to conducting research, and to suggest future research topics and methods in this area.

1.1. Previous research on CEC and psychological health

Early psychological studies used a range of comparative designs and methods to determine that CEC experience was stressful for extended temporal periods, although not necessarily at levels indicative of clinical impairment (Baum and Flemming, 1993; Havenaar and Van den Brink, 1997; Bowler et al., 1994). Theoretical models suggested similarities between symptoms of CEC-induced chronic stress and posttraumatic stress disorder (PTSD), particularly in regard to the chronic ambiguity, invisibility, and subsequent hypervigilance associated with exposure and potential health effects (Edelstein, 2018; Vyner, 1988). Researchers highlighted that the stage sequence in CEC is often of a cyclical nature, differing from the linear trajectory of natural disaster stages (Edelstein, 2018).

Past literature suggests that the material dimension of impact (e.g., real or perceived health effects, property loss or devaluation) is a significant contributor to the stress of the CEC experience (Edelstein, 2018). Further, Vyner (1988) proposed that the social dimension of responses to CEC was the most important factor for determining the risk of severe psychological health outcomes. Specifically, he identified three social risk factors that we designate processes of institutional delegitimization: (1) denial (or framing as a “non-issue” (Reich, 1991; Calloway et al., 2020)) of the severity and potential impact of CEC by corporations, government, or public health professionals; (2) problematic relationships with healthcare providers who are unfamiliar with local histories of CEC and may attribute patient concerns to somatic symptom or illness anxiety disorders (Calloway et al., 2020); and (3) indirect or direct victim-blaming processes such as attributing health effects to lifestyles choices rather than CEC (Checker, 2007).

Beyond variation of these situational factors, studies have consistently documented diverging psychological responses to CEC. Some community members exhibit a “maximalist” reaction of distress, and others a “minimalist” reaction of little impact (Fowlkes and Miller, 1987). It has been noted that women often display more pronounced stress reactions to CEC and technological disasters than men (Gibbs, 1989).

Evidence that CEC exposure is stratified by race/ethnicity and socioeconomic status is provided in U.S. national-level longitudinal studies of hazardous waste facility sitings (Mohai and Saha, 2015), national- and state-level studies of Superfund site locations (Kramar et al., 2018), and case studies of metropolitan areas (Pulido, 2000). An exposure-disease paradigm suggests that disadvantaged groups are at greater risk for suffering physical health consequences when exposed to contaminants because they are chronically subjected to greater stressors (Gee and Payne-Sturges, 2004; Morello-Frosch and Shenassa, 2006). Exposures to stress and environmental contaminants can interact, leading to worse health risks than either exposure on its own (McEwen and Tucker, 2011). Some scholars have called this interaction a "double jeopardy" for disadvantaged communities (Morello-Frosch and Shenassa, 2006).

Social and environmental stressors are associated with higher allostatic load, a form of physiological wear measured as a composite of physical biomarkers (McEwen and Tucker, 2011). Through allostatic overload, chronic stress can lead to several health risks, including hypertension, coronary heart disease, and autoimmune disorders, which may also make individuals more susceptible to the effects of contaminants (Dhabhar, 2011). Chronic stress may interact with toxicant exposure to produce worse health outcomes, in part by amplifying the adverse effects of a toxicant (e.g., by compromising the immune system, especially if contaminants independently impair immune functioning (Gee and Payne-Sturges, 2004)).

To summarize what is known from the existing literature, the experience of CEC can have negative impacts on psychological health, with qualities that differentiate it from the experience of natural disasters, and women and members of disadvantaged social groups are disproportionately vulnerable to negative psychological and physical health impacts. However, a central question has not been previously addressed using a systematic review method: What is the severity of the psychological health impacts caused by CEC, and what risk factors may contribute to psychological health impacts?

2. Methods

We conducted a systematic review and meta-analysis of available quantitative findings from 1995 to 2019 as a synthesis of what is already known and impetus to future research. Given natural barriers to research in this area, it was anticipated that the relevant quantitative empirical evidence would be somewhat limited with an acknowledged risk of bias.

2.1. Study selection and data extraction

The available quantitative literature was examined using a systematic review protocol (PRISMA-P checklist) that was developed iteratively a priori (Moher et al., 2009). Due to project time constraints associated with federal government scientific clearance processes, the protocol for this review was not registered, but is available in Supplemental Materials (Appendix A). The present systematic review and meta-analysis adhered to this protocol, but only represent one part of the broader project carried out by ATSDR. Specifically, the present review only reports methods and results pertinent to Research Question 2 (Item #7) in the a priori PRISMA-P checklist. Literature searching occurred from June to August of 2019. We searched Embase, Medline, PsycINFO, Scopus, TOXNET, and Web of Science for peer-reviewed literature. We searched Deep Blue, WorldCat, WorldWide Science, and PROQUEST, as well as the ATSDR, CDC, and SAMHSA websites for grey literature (see Appendix B in Supplemental Materials for all search terms).

Studies needed to include quantitative analyses on the psychological stress impacts of experiencing CEC (including living near contaminated sites), provide findings that examined an identified community (or set of communities), and be conducted within a developed nation (Human Development Index 2018 ≥0.90). All quantitative study designs were allowed. Further, studies had to include an operationalization of the exposure/contamination experience, a measure of psychological health including anxiety, stress, depression, or post-traumatic stress, and had to be conducted from 1995 to 2019 (in order to update a major synthesis of this literature conducted in 1995 by an ATSDR-convened expert panel (Tucker, 1998)).

The research team decided to narrowly focus the operationalization of CEC, which resulted in excluding occupational exposures and major catastrophic events. While occupational exposures can be chronic in nature, these studies do not typically address the psychosocial impact of CEC as a community-level hazard. Occupational exposures also tend overall to induce less psychological stress compared to involuntary community exposures (Lebovits et al., 1986). Well-researched, major catastrophic events (e.g., September 11 terrorist attacks, Fukushima disaster, Deepwater Horizon oil spill) present highly unique aspects that might influence psychosocial outcomes to a degree that would be atypical for most communities' CEC experience. We excluded such events because (1) they were characterized by heavily-mediatized, widespread social narratives, and (2) they had clearly catastrophic and traumatic impacts on a large number of lives or livelihoods. Consequently, they could be expected to have large psychological effects, which we would not expect to generalize to CEC experiences which lack these aspects. Furthermore, because there are large bodies of extant literature on each of these events, we believed that searching for studies of other, lesser-known experiences would make a more important scientific contribution.

Articles were screened by five researchers at the title, abstract, and full-text level using DistillerSR software (Evidence Partners, Ottawa, Ontario). One researcher screened each article at the title level and abstract level. Hand searching was done on reference lists of all studies that made it past abstract screening. We also reached out to corresponding authors of included papers published in the past 5 years for clarification on effect size statistics when necessary. This resulted in the inclusion of 2 effect sizes from 2 separate papers that had appeared in the systematic review, but that did not report enough information to calculate the effect sizes. One author that we reached out to alerted us of a paper that we did not find in our initial literature search, but that fit our inclusion criteria. We included this paper in the systematic review and included one effect size from this paper in the meta-analysis. Relevant hand-searched empirical studies and grey literature were included into the full-text screen, though no grey literature ended up being included in the present review. For the full-text screen, two researchers screened each article. Screening disagreements were discussed among the group until consensus was reached. Relevant qualitative, theoretical, review, and non-empirical grey literature papers were flagged during searching and retained separately for inclusion in a separate narrative review project (Sullivan et al., under review). Relevant data were extracted from all articles that made it past full-text screening using data extraction forms created in DistillerSR. The full evidence table with all extracted data is available upon request, but a simplified version can be found in Table 1 (Behbod et al., 2014; Bevc et al., 2007; Cline et al., 2014; Couch and Mercuri, 2007; Cutchin et al., 2008; Downey and Van Willigen, 2005; Elliott et al., 1997; Elliott et al., 2018; Fitzgerald et al., 2008; Fortenberry et al., 2018; Ginsberg et al., 2012; Grasmück and Scholz, 2005; Greve et al., 2005; Greve et al., 2007; Ha et al., 2018; Hastrup et al., 2007; Korol et al., 1999; Kruger et al., 2017a; Kruger et al., 2017b; Kruger et al., 2017c; Levy et al., 2004; Matthies et al., 2000; McCarron et al., 2000; McIntyre et al., 2018; Peek et al., 2009; Rehner et al., 2000;

Reif et al., 2003; Sansom et al., 2017; Santiago-Rivera et al., 2007; Schade et al., 2015; Schade et al., 2016; Song et al., 2018; Ushijima et al., 2004; Vandermoere, 2006; Vandermoere, 2008; Verschuur et al., 2007; Verschuur et al., 2008; Weinert et al., 2011; Whiteman et al., 1995; Zierold et al., 2004; McComas and Trumbo, 2001).

2.2. Risk of Bias

Risk of Bias assessments for the included literature were made using the Risk of Bias Assessment Tool for Nonrandomized Studies (RoBANS) (Kim et al., 2013). However, the findings were not weighted based on the risk of bias assessment. Many well-established and widely-used tools for assessing risk of bias in systematic reviews are specifically designed to assess randomized controlled trials (e.g., the Cochrane Collaboration tool (Higgins and Thomas, 2019)). However, the area of research reviewed here does not permit this methodology. Alternatively, the RoBANS was designed to assess risk of bias in a variety of non-randomized study designs. The RoBANS assesses risk of bias in 6 domains: selection of participants, consideration of confounding variables, measurement of exposure, blinding of outcome assessments, handling of incomplete outcome data, and selective outcome reporting. Due to variation in reporting standards, it was difficult to judge most studies in this literature for the last three domains; accordingly, low versus high risk scores were assigned to studies based on their majority score for the first 3 domains. Overall RoBANS assessment scores for each study can be found in Table 1. The findings were not weighted based on the risk of bias assessment for two reasons. First, there are limitations to the RoBANS as a tool for grading evidence in this specific research area. Second, this is an emerging and challenging field where most studies are expected to have a relatively high risk of bias due to inherent challenges.

2.3. Methods of analysis

We conducted meta-analyses to assess the impact of CEC on the experience of negative psychological health outcomes. Studies from the systematic review were included in the meta-analysis if they reported sufficient statistical information in order to extract effect sizes, had an independent variable that assessed objective or subjective experience of contamination, and had a dependent variable that assessed psychological stress. We also reached out to corresponding authors from papers published in since 2015 for clarification on statistics where necessary to compute effect sizes. We conducted a meta-analysis of random effects using a multilevel linear model of mixed effects. All effect sizes were converted to Pearson's r correlation coefficients. We calculated summary estimates for each dependent variable separately, as well as for all effect sizes together. Further, we present a narrative synthesis of important findings from the systematic review on potential risk factors that could not be included in the meta-analysis.

Independent variables utilized for the meta-analysis fell into six categories assessing (extent of) CEC experience: Objective exposure (k = 27), time (k = 2), distance (k = 6), health (k = 11), subjective exposure (k = 13), and proxy measures (k = 1). *Objective exposure* measures included indicators such as the amount of a given contaminant in a water source. Objective exposure independent variables also included studies that compared an "exposed" case group to a "non-exposed" control group. *Time* included measures of how long an individual was exposed to a given contaminant. *Distance* measures assessed how far an individual was from the contaminated site/event. *Health* included both objective measures of health effects experienced by individuals that were associated with contamination (e.g., prevalence of Minamata disease, lung function), and subjective measures of perceived connections between health and contamination. *Subjective exposure* measures included subjective concerns and uncertainties about the given contamination event, or subjective assessments of how much of the contaminant the participant was exposed to. The *proxy measure* for contamination used in one study was the perceived deleterious impacts of CEC on social relationships.

Dependent variables fell into 4 categories: anxiety ($k = 6$), general stress ($k = 36$), depression symptoms ($k = 10$), and PTSD symptoms ($k = 8$). The *Anxiety* measures included such scales as the State-Trait Anxiety Scale (STAS) and various health anxiety scales. The *General Stress* measures varied widely, including the Perceived Stress Scale (PSS), various versions of the General Health Questionnaire (GHQ), sleep quality and duration measures, and other more event-specific measures for concern about the impacts of the contamination. *Depression* measures included the Beck Depression Inventory (BDI), the Center for Epidemiological Studies Depression Scale (CES—D), and other non-specified measures. *PTSD* measures included the Impact of Events scale (IES), the Short Screening Survey for PTSD, and other non-specified or interview measures.

3. Results

Fig. 1 depicts our selection process, which ultimately yielded 41 studies for inclusion in the systematic review. See Table 1 for an evidence table of all studies included in the systematic review. Of these, 33 studies met the above criteria to be included in the meta-analysis, including 60 effect sizes. Most studies examined communities in the United States, although 32% came from either Australia, Canada, Europe, or South Korea. The majority of studies (59%) examined communities experiencing CEC in the form of (potential) exposures due to historic or ongoing industrial activity (e.g., Superfund site communities), although a number also examined exposures that occurred in the wake of technological accidents (24%) or due to proximity to a landfill/waste site (12%). Only 2 of the studies (5%) examined exposures due to radiation or nuclear activity.

The majority of studies (61%) were cross-sectional in design. Evaluating the studies using the RoBANS tool, this literature clearly exhibits a risk of bias, indexed (for instance) by the fact that 46% of the studies either relied on self-reported indices of exposure or had no index of individual exposure levels, and only about one-quarter of studies used either a case-control design (17%) or a before-and-after design (7%). One small but notable advance over the earlier literature is that at least one study established an effect of CEC on psychological stress while controlling for potential secondary gains and strategic over-reporting in the context of litigation (Greve et al., 2005). Overall, the characteristics of the studies reflect methodological challenges often inherent to the study of psychological outcomes of CEC. While due caution should be used when extrapolating from these findings, this body of literature still offers valuable lessons to inform future research and practice.

Less than half of studies reported physical health outcomes. Among these, many are limited by self-report. Despite these limitations, there is some suggestive evidence supporting allostatic load theory in the context of CEC. A study of the CEC-impacted, racial minority Wingate community in Fort Lauderdale observed bidirectional links between physical and psychological health (Bevc et al., 2007); a study of the Texas City community yielded an association between contamination concerns and physical health specifically in Black participants (Cutchin et al., 2008); and a survey of 19 Wisconsin towns found that higher levels of arsenic in private well water were associated both with higher reported levels of depression and adverse cardiac effects (Zierold et al., 2004). At least one of the present studies directly established CEC effects on physiological stress indicators, such as inflammation and viral reactivation (Peek et al., 2009).

3.1. Possible risk factors

Earlier literature suggests there are several factors that moderate the likelihood of psychological stress among community members. Our review offers further support for two primary risk factors identified in earlier studies. Along the material dimension, the presence (versus absence) of health effects and concerns in the individual, family, or community appears to be a risk factor for negative psychological health outcomes. 29% of studies reported a significant association between health effects or concerns and psychological health. Of these, 6 studies reported sufficient statistical information, allowing us to calculate 11 effect sizes for the effect of contamination-related health concerns on all psychological health outcomes. As a supplementary analysis to the main meta-analyses reported below, we conducted a meta-analysis of random effects using a multilevel linear model of mixed effects to assess the impact of health concerns on psychological health (see Table 2 and Fig. 2 for summaries of the results). Pearson's r effect sizes ranged from 0.04 to 0.47 with a raw mean of 0.28 ($SD = 0.17$, median = 0.34). The meta-analysis revealed a small-to-medium effect of health concerns on all psychological health outcomes: $z = 0.33$, se = 0.14, 95% CI [0.02, 0.65], $p = .040$. A Fisher's z of 0.33 is roughly equivalent to a Pearson's r of 0.32 (95% CI [0.02, 0.57]).

Along the social dimension, an important moderator is the experience of various processes of *institutional delegitimization*: feeling that responsible or socially protective institutions have denied or misattributed one's concerns about CEC-related health effects. Perceived poor communication from officials (Schade et al., 2016) and credibility of public health, media, and industry (McComas and Trumbo, 2001) significantly impacted distress. Notably, 50% of sampled residents in Flint, MI reported that feeling overlooked by responsible institutions was a major stressor (Fortenberry et al., 2018).

In the accumulated literature, women (compared to men) displayed statistically significantly worse psychological health impacts in 24% of the total studies. Although these studies do not speak to the mechanism(s) behind this effect, women may be at greater risk for stress along both the material dimension – women often have the caregiver role for health issues within the family and may be more alert and aware of new problems – and the social dimension – they may be especially likely to experience delegitimization through dismissal of their concerns as "irrational" (Brown and Ferguson, 1995).

3.2. Effects of chronic contamination on psychological stress

See Table 3 for a summary of results and Fig. 3 for a forest plot of these meta-analyses. Pearson's *r* effect sizes ranged considerably from <0.002 to 0.63. The raw mean of effect sizes was 0.26 (SD = 0.15, median = 0.25). We converted the Pearson's *r* correlations into Fisher's *z* to conduct the meta-analysis ($M = 0.28$, $SD = 0.17$, median = 0.26). The final overall *N* in the 33 studies was 25,858. However, it is important to note that over 34% ($n = 8826$) came from a single study on community radiation impacts in South Korea (Ha et al., 2018). Removing this study from the meta-analysis did not substantively change the outcome (Δ Fisher's $z < 0.01$).

We conducted a meta-analysis of random effects using a multilevel linear model of mixed effects in order to account for nonindependence of effect sizes from the same studies. We found a small-to-medium effect of contamination on all psychological outcomes, including anxiety, general stress, depression, and PTSD: $z = 0.22$, se = 0.06, 95% CI [0.10, 0.33], $p < .001$. A Fisher's *z* of 0.22 is roughly equivalent to a Pearson's *r* of 0.21 (95% CI [0.10, 0.32]).

We also conducted the meta-analyses separately for each of the different dependent variables. We found a small-to-medium effect of chronic contamination on anxiety ($z = 0.23$, se = 0.08, 95% CI [0.02, 0.44], $p = .035$), a small-to-medium effect of chronic contamination on general stress ($z = 0.21$, se = 0.06, 95% CI [0.09, 0.33], $p = .001$), a small-to-medium effect of chronic contamination on depression symptoms ($z = 0.20$, se = 0.07, 95% CI [0.03, 0.36], $p = .023$), and a medium effect of chronic contamination on PTSD symptoms ($z = 0.33$, se = 0.07, 95% CI [0.17, 0.49], $p = .002$). We conducted Bayesian Information Criterion model comparisons of random effects models that either did or did not account for nonindependence to find the best fitting model. In all cases, the models presented above were the best fit for the data (ΔBIC >7).

3.3. Analysis of heterogeneity

Each of the meta-analyses showed considerable heterogeneity of effect sizes. For the effect size of chronic contamination on all psychological outcomes, there was substantial heterogeneity: Q = 679.42, $p < .001$, $I^2 = 94.21\%$. More of this heterogeneity was due to within-study variation ($I^2 = 62.89\%$) than between-study variation ($I^2 = 31.33\%$). The higher within-study variation likely reflects the inclusion of multiple different independent and dependent variables. In order to assess between-study variation more meaningfully, we ran separate tests of heterogeneity on subsets for each of the three dependent variables. There was also substantial heterogeneity for the pooled effect size of chronic contamination on only anxiety (Q = 24.69, $p < .001$, $I^2 = 83.46\%$), on only general stress (Q = 473.45, $p < .001$, $I^2 = 94.40\%$), on only depression (Q = 110.32, $p < .001$, $I^2 = 91.67\%$), and on only PTSD (Q = 29.52, $p < .001$, $I^2 = 82.12\%$). The substantial heterogeneity of each of these analyses is not surprising, given the broad range of methods used to measure the dependent variables and the heterogeneity inherent to each of the CEC events represented by this literature. It is important to interpret the results of these meta-analyses with caution, maintaining awareness of the unique nature of each of the CEC events represented in these analyses, as well as the lack of consistency in how exposure to CEC and psychosocial health consequences are measured in this literature. Funnel plot summaries of the heterogeneity of the pooled effect sizes are available in the Supplemental Materials (Fig. S1).

4. Discussion

Our review suggests that CEC has a robust impact on anxiety, general stress, depression symptoms, and PTSD symptoms. Despite limitations, it seems unlikely, based on the meta-analysis, that there is a null or negligible average effect of CEC on psychological health. Further, the assembled studies indicate that the presence of concerns about possible health impacts or actual health impacts (attributed to contamination) on the individual or their family members is a robust risk factor for the psychological health impacts of CEC. This finding is meaningful considering that not all of the studies assessed these variables. As prior studies have suggested (Lebovits et al., 1986), our findings reinforce the notion that, within a community experiencing CEC, those with health problems they attribute to contamination are the most likely to experience negative psychological outcomes. Our review provides evidence that social processes of institutional delegitimization of concerns may act as secondary impacts of CEC, and may in some instances have a greater influence on psychological health than the material dimension of health concerns. In sum, our review supports the conclusion that those individuals who attribute physical health effects to exposure, and who feel that their concerns are being de-legitimized by culpable or responsible institutions, are most at risk for psychological health impacts as a consequence of CEC.

As noted, this review represents a major update to a synthesis of the literature based on an ATSDR-convened expert panel in 1995 (Tucker, 1998). Results from the present review support a number of findings from this report, though the former is somewhat more limited in scope due to the exclusive inclusion of quantitative literature. Specifically, the original expert panel report and the present review converge in the findings that (1) experiencing CEC can have negative effects on psychological health, (2) the perceived presence of physical health impacts from CEC can contribute to worse psychological health impacts, and (3) institutional delegitimization of community concerns can further exacerbate psychological health impacts of CEC. One new finding from the present review is that women may be particularly susceptible to the psychological health impacts of CEC. The present review represents an important advancement beyond the original expert panel report as the first systematic review and meta-analysis of the psychological health impacts of CEC.

One of the major advances in the literature on psychological health impacts of CEC in recent decades has been the documentation of environmental injustice. The literature accumulated for the present review does not provide substantial additional documentation of such effects, simply because the studies were generally not designed to test for them: most study samples were racially homogenous and hence inadequate for tests of moderation. However, qualitative studies that were separately gathered as part of the systematic review documented perceived experiences of institutional delegitimization that are attributed to indirect or even direct racism (Sullivan et al., under review). There are well-documented health disparities based on both race/ethnicity and lower socioeconomic status, and recent evidence that the effect of socioeconomic status on mental health is environmental in origin (Nuru-Jeter et al., 2018). These findings, combined with the systematic review results presented here, suggest that the risk of psychological health impacts is elevated for disadvantaged group members (racial/ethnic minorities and lower socioeconomic status) due to: (1) increased likelihood of experiencing CEC; (2) increased likelihood of adverse health effects that may be attributed to CEC; and (3) increased likelihood of experiencing institutional delegitimization.

4.1. State of the literature

The findings of this systematic review and exploratory meta-analysis must be interpreted with caution given the methodological limitations present in the existing literature in this area of research. Five factors influencing heterogeneity and/or risk of bias should be considered. First, the independent variable of CEC experience and the dependent variable of psychological health were assessed in highly diverse ways across the studies, often using measures that have not been well validated. This reflects the variability inherent in the CEC events represented in the literature reviewed here. Second, in many studies, self-report was used for either the independent variable, the dependent variable, or both. This may present limitations particularly in situations where an impacted community perceives that they may gain from over-reporting exposures or health consequences. Third, sampling limitations occurred in many studies, with almost all studies using convenience samples. Participants were often recruited via word-of-mouth, in clinics, or at community meetings among individuals more likely to already be concerned about CEC. These selection biases could artificially inflate observed effect sizes. Fourth, the relative lack of case-control, longitudinal, or pre-post designs limits the ability to make causal inferences. This suggests that many of these studies did not have a meaningful comparison group or baseline estimate of the psychosocial health of an impacted community prior to contamination. This is a common methodological challenge in research on different types of environmental disasters (Norris, 2006). Fifth, many studies used only bivariate analyses, so potentially confounding variables (e.g., socioeconomic status) may not be sufficiently addressed in the literature. Due to such limitations of the literature, it is important to interpret the meta-analysis presented here with caution, and as an impetus for future improved research.

Still, we interpret the presence of small-to-medium effects in the exploratory meta-analysis as reinforcing prior research and further supporting that there is a robust, detectable impact of CEC on individual psychological health in an impacted community. Much of the research indicates that residents of CEC communities show variable psychological responses, and it is important to bear in mind that our meta-analytic approach averages across these variable responses. The small-to-medium effects observed are consistent with the interpretation that while many people’s psychological health is at least somewhat impacted by CEC, only a subset are likely to experience major psychological difficulties; and in many of the reviewed studies a subset of participants met screening criteria (as indicated by self-report measures) for a clinical diagnosis. The relatively larger effect for PTSD outcomes is notable but possibly due to the fact that the majority of PTSD effects came from studies in which a technological disaster was the source of CEC. The effect of CEC on depression ($r = 0.20$) is also notable. By comparison, in a meta-analytic investigation of the effect of negative life events on depression in older adults, bereavement, severe illness, and financial strain all had relatively smaller effects (Kraaij et al., 2002); and a methodologically rigorous pre/post study showed that a natural disaster had a smaller effect ($r = 0.15$) on depression rates (Ginexi et al., 2000).

4.2. Future directions

Looking forward, we suggest a number of methodological considerations for future research in this area. More rigorous study designs, especially prospective cohort, longitudinal, and comparative designs ranging across multiple, demographically heterogeneous communities, would better establish the true extent of the psychological health impact of CEC and its moderating factors. Relatedly, future studies should consider more rigorous sampling methodologies that reduce selection biases, such as random sampling in an impacted area or stratified sampling to compare impacted and control communities. In general, greater consistency in measurement of constructs such as experienced stress and PTSD symptoms would also be desirable. It would be beneficial if future research could better triangulate on psychological health outcomes using both self-report and physiological methods. Despite the established importance of allostatic load and the physical health effects of chronic stress (McEwen and Tucker, 2011), we did not find many studies in our systematic review that permit determination of toxicant-stress interactions on health. This is because few studies simultaneously and adequately assess (1) actual and perceived toxicant exposure, (2) both physical and psychological health outcomes, and (3) longitudinal processes in the context of a CEC-impacted community. Future studies should consider other secondary sources of stress faced by these communities (e.g., community conflict, financial losses from dropping property values or the destruction of arable land). Finally, future studies should assess other social determinants of health (e.g., socioeconomic status, education, neighborhood characteristics, access to healthcare) and either control for these factors in analyses, or assess the moderating role that these factors may play in the association between CEC and psychological health outcomes.

To summarize our recommendations for addressing the shortcomings of the extant literature, we suggest that future work should operationalize exposure both objectively and subjectively, operationalize psychological health using physiological indicators as well as self-report measures, assess exposure, psychological health, and physical health outcomes simultaneously, and sample more rigorously from multiple communities simultaneously in order to generalize across experiences or employ longitudinal methods to assess temporal trends in CEC experience.

4.3. Conclusion

The literature we have assembled for this review has broad implications for the psychological health impacts of CEC. We suggest that any successful public health assessment or intervention in communities impacted by CEC must take seriously the psychological health impacts that individuals may face. Of equal import is an understanding of the potential risk factors for worse psychological health outcomes: institutional delegitimization and real or perceived health impacts. It is pivotal that public health officials and local community leaders validate the psychological experiences of impacted communities to adequately address the impact of CEC.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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HIGHLIGHTS

- Psychological health impact of chronic environmental contamination is understudied.
- Contamination was associated with anxiety, general stress, depression, and PTSD.
- Institutional delegitimization and physical health impacts may be risk factors.

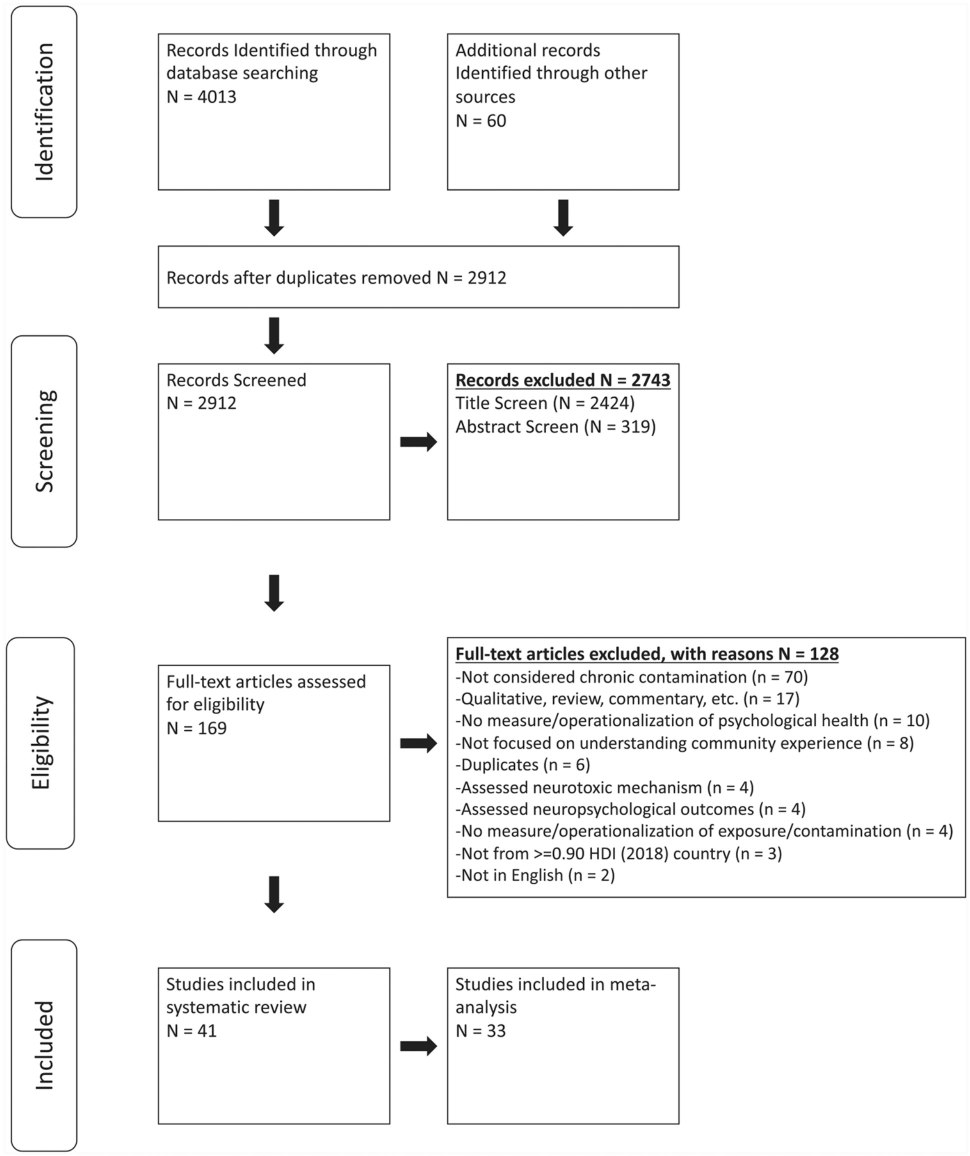

Fig. 1.

Screening and selection process for the systematic review.

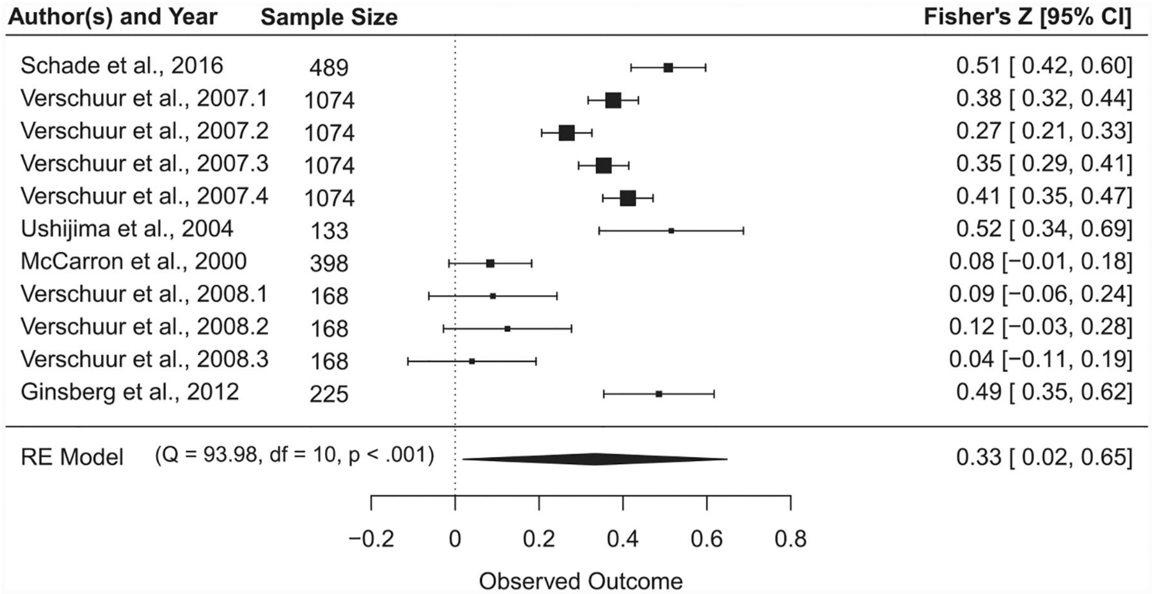

Fig. 2.

Effect size forest plot for meta-analysis of the effect of contamination-related health concerns on all psychological health dependent variables. Note. Each individual Fisher's *z* effect size is presented as a black square with 95% CI error bars. Size of the square for each individual effect size represents relative weight based on sample size. The large black rhombus represents the aggregated Fisher's *z* effect size. The width of the rhombus represents the 95% CI around the effect size.

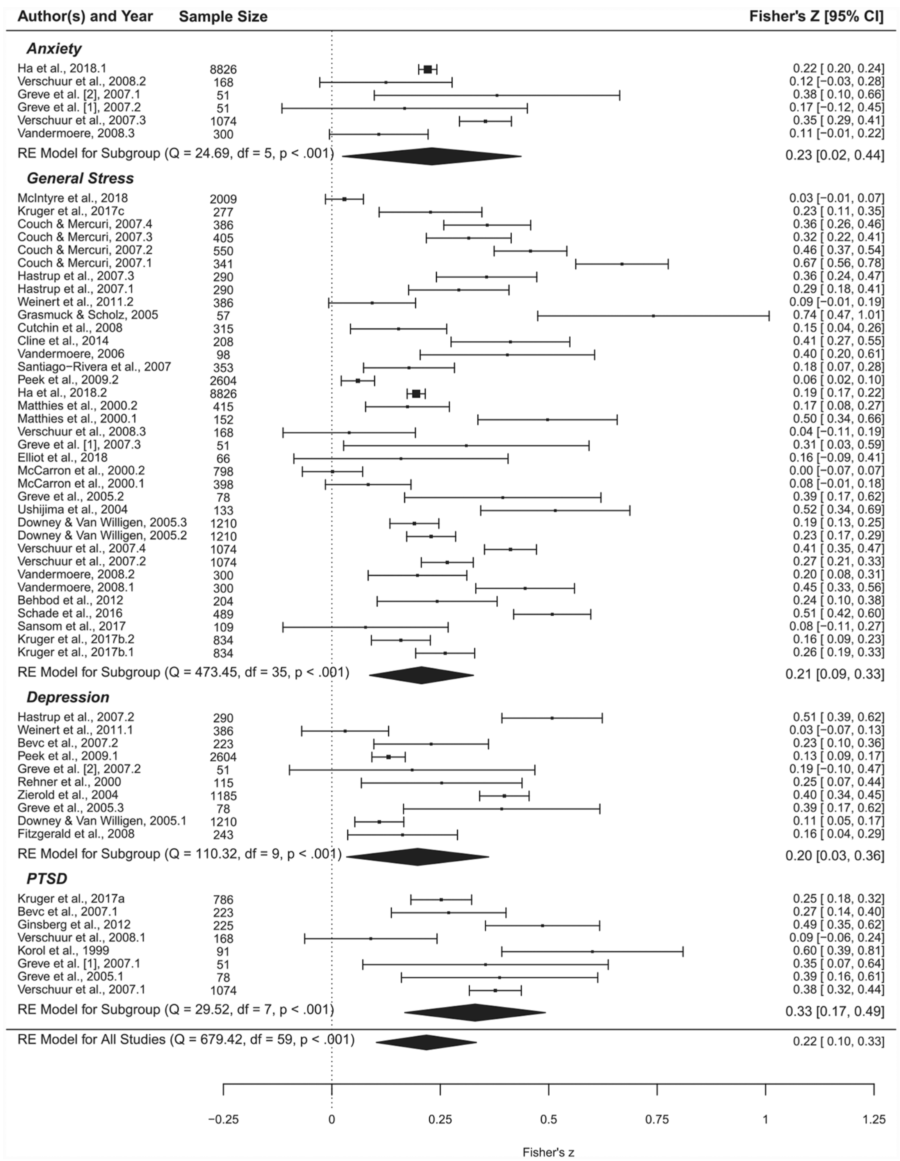

Fig. 3.

Effect size forest plot for meta-analyses, separated by psychological health outcome. Note. Each individual Fisher's *z* effect size is presented as a black square with 95% CI error bars. Size of the square for each individual effect size represents relative weight based on sample size. Large black rhombuses represent the aggregated Fisher's *z* effect sizes for Anxiety, General Stress, Depression, PTSD, and all outcomes combined. The width of each rhombus represents the 95% CI around the effect size.

Table 1

Empirical quantitative studies on psychological stress as a function of chronic environmental contamination, selected through the systematic review.

Publication	Contamination event/source	Region	Study design	Independent variable (s)	Dependent variable (s)	Risk of bias	*n*	*r*
Behbod et al. (2014)	Tert-butyl mercaptan exposure, tank leak	Prichard, AL, US	Cross-sectional	Distance	General stress	Low	204	0.24
Bevc et al. (2007)[b]	Landfill/waste site	Ft. Lauderdale, FL, US	Cross-sectional	Subjective	Depression,	Low	223	0.230
					PTSD			.26
Cline et al. (2014)	Asbestos exposure, industrial activity	Libby, MT, US	Cross-sectional	Proxy measure	General stress	High	208	0.39
Couch and Mercuri (2007)[b]	Benzene exposure from industrial activity	Houston, TX, US	Case-control	Objective	General stress	Low	341	0.580
							550	.430
							386	.340
							405	.31
Cutchin et al. (2008)	Industrial activity and refinery explosion	Texas City, TX, US	Before-and-after	Distance	General stress	Low	315	0.15
Downey and Van Willigen (2005)[b]	Proximity to chronic industrial activity	Chicago & neighboring counties in IL, US	Cross-sectional	Objective	General stress	Low	1210	0.230
								.190
					Depression			.11
Elliott et al. (1997)[a]	Landfill	Milton, ON, CA	Before-and-after			High		
Elliott et al. 2018	Proximity to unconventional oil & gas wells	Belmont County, OH, US	Cross-sectional	Objective	General stress	Low	66	0.16
Fitzgerald et al. (2008)	Polychlorinated biphenyl exposure, water, industrial activity	Hudson River Area, NY, US	Cross-sectional	Objective	Depression	Low	243	0.16
Fortenberry et al. (2018)[a]	Lead exposure, water	Flint, MI, US	Cross-sectional			High		
Ginsberg et al. (2012)	Chlorine exposure, railway accident	Graniteville, SC, US	Cross-sectional	Health	PTSD	Low	225	0.45
Grasmück and Scholz (2005)	Heavy metal exposure, soil, industrial activity	Dornach, Switzerland	Case-control	Subjective	General stress	High	57	0.63
Greve et al. (2005)[b]	Toxic waste cloud, railway accident	Eunice, LA, US	Case-control	Objective	General stress	Low	78	0.370
					Depression			.370
					PTSD			.37
Greve et al. (2007)[b]	Toxic waste cloud, railway accident	Eunice, LA, US	Case-control	Objective	Anxiety	Low	51	.17[c]
					General Stress			.30[c]

Publication	Contamination event/source	Region	Study design	Independent variable (s)	Dependent variable (s)	Risk of bias	*n*	*r*
					PTSD			.34[c]
					Anxiety		51	.36[d]
					Depression			.18[d]
Ha et al. (2018)[b]	Heavy traffic roads contaminated by radiation	Seoul, South Korea	Cross-sectional	Subjective	Anxiety	Low	8826	0.220
					General stress			.19
Hastrup et al. (2007)[b]	Hazardous dumping, historic industrial activity	Anonymous	Case-control	Objective	General stress	Low	290	0.280
		Appalachian						.340
		Community			Depression			.47
Korol et al. (1999)	Nuclear waste, government activities	Fernald, OH, US	Cross-sectional	Distance	PTSD	High	91	0.54
Kruger et al. (2017a)	Lead exposure, water	Flint, MI, US	Cross-sectional	Subjective	PTSD	High	786	0.25
Kruger et al. (2017b)[b]	Lead exposure, water	Flint, MI, US	Cross-sectional	Subjective	General stress	High	834	0.250
								.16
Kruger et al. (2017c)	Lead exposure, water	Flint, MI, US	Cross-sectional	Subjective	General stress	High	277	0.22
Levy et al. (2004)[a]	Environmental exposures, public housing	Boston, MA, US	Cross-sectional			High		
Matthies et al. (2000)[b]	Benzo(*a*)pyrene exposure, soil, industrial activity	Dortmund-Dorstfeld, Germany	Case-control	Subjective	General stress	Low	152	0.460
				Objective			415	.17
McCarron et al. (2000)[b]	Landfill, chromium waste	Glasgow, Scotland	Case-control	Health	General stress	Low	398	0.080
				Objective			798	.001
McComas and Trumbo (2001)[a]	Landfills, chronic industrial activity	Various communities, NY State, US	Cross-sectional			High		
McIntyre et al. (2018)	Chronic industrial activity	Various communities, Australia	Cross-sectional	Distance	General stress	Low	2009	0.03
Peek et al. (2009)[b]	Chronic industrial activity	Texas City, TX, US	Cross-sectional	Subjective	General stress	Low	2604	0.060
					Depression			.13
Rehner et al. (2000)	Methyl parathion exposure, pesticide use	Jackson County, MS, US	Follow-up cohort	Time	Depression	Low	115	0.25
Reif et al. (2003)[a]	Trichloroethylene exposure, water	Denver, CO, US	Cross-sectional			Low		
Sansom et al. (2017)	Waste sites and industrial activity	Houston, TX, US	Cross-sectional	Time	General stress	High	109	0.08
Santiago-Rivera et al. (2007)	Polychlorinated biphenyl exposure, water	Akwasasne Mohawk reservation, NY, US	Cross-sectional	Objective	General stress	Low	353	0.18

Publication	Contamination event/source	Region	Study design	Independent variable (s)	Dependent variable (s)	Risk of bias	*n*	*r*
Schade et al. (2015)[a]	4-methylcyclohexane methanol exposure, solvent spill	Charleston, WV, US	Retrospective follow-up			High		
Schade et al. (2016)	4-methylcyclohexane methanol exposure, solvent spill	Charleston, WV, US	Retrospective follow-up	Health	General stress	High	489	0.47
Song et al. (2018)[a]	Hydrogen fluoride exposure, spill/transport accident	Gumi, South Korea	Cross-sectional			Low		
Ushijima et al. (2004)	Methylmercury exposure, water, industrial activity	Minamata City, Japan	Follow-up cohort	Health	General stress	High	133	0.47
Vandermoere (2006)	Heavy metal exposure, soil, industrial activity	Kouterwijk, Belgium	Cross-sectional	Subjective	General stress	High	98	0.38
Vandermoere (2008)[b]	Heavy metal exposure, soil, industrial activity	Kouterwijk, Belgium	Case-control	Objective	General stress	High	300	0.420
								.190
					Anxiety			.11
Verschuur et al. (2007)[b]	Rumored uranium exposure, airplane accident	Amsterdam, Netherlands	Before-and-after	Health	General stress	High	1074	0.260
								.390
					Anxiety			.340
					PTSD			.36
Verschuur et al. (2008)[b]	Rumored uranium exposure, airplane accident	Amsterdam, Netherlands	Follow-up cohort	Health	Anxiety	High	168	0.120
					General Stress			.040
					PTSD			.09
Weinert et al. (2011)[b]	Asbestos exposure, industrial activity	Libby, MT, US	Cross-sectional	Distance	General stress	High	386	0.090
					Depression			.03
Whiteman et al. (1995)[a]	Lead/chemical exposure, mining and industry	Kinston, Australia	Follow-up cohort			High		
Zierold et al. (2004)	Arsenic exposure, water	Sinnipee/St. Peter, WI, US	Cross-sectional	Objective	Depression	High	1185	0.38
					$k = 60$		$N = 25{,}858$	$r = 0.26$

[a] Studies not included in the meta-analysis.

[b] Includes multiple effects from the same participants.

[c] Effects from child participants.

[d] Effects for parents of child participants.

Table 2

Summary of meta-analysis of the effect of contamination-related health concerns on all psychological health dependent variables.

Independent variable	***k***	**Fisher's *z* [95% CI]**	**Fisher's *z* *p*-Value**	**Pearson's *r* [95% CI]**	**Cochrane's *Q***	**Cochrane's *Q* *p*-Value**	I^2
Health	11	0.33 [0.02, 0.65]	0.040	0.32 [0.02, 0.57]	93.98	<0.0001	95.30%

Note. This table presents a summary of the meta-analysis for the effect of contamination-related health concerns on all psychological health dependent variables. All Fisher's *z* estimates were attained from multilevel linear models of mixed effects. Each Fisher's *z* was converted to Pearson's *r* for ease of interpretation.

Table 3

Summary of meta-analyses split by dependent variable.

Outcome	*k*	Fisher's *z* [95% CI]	Fisher's *z* *p*-Value	Pearson's *r* [95% CI]	Cochrane's *Q*	Cochrane's *Q* *p*-Value	I^2
Anxiety	6	0.23 [0.02, 0.44]	0.035	0.23 [0.02, 0.41]	24.69	<0.001	83.46%
General Stress	36	0.21 [0.09, 0.33]	0.001	0.20 [0.09, 0.32]	473.45	<0.0001	94.40%
Depression	10	0.20 [0.03, 0.36]	0.023	0.20 [0.03, 0.35]	110.32	<0.0001	91.67%
PTSD	8	0.33 [0.17, 0.49]	0.002	0.32 [0.17, 0.46]	29.52	<0.001	82.12%
Overall	60	0.22 [0.10, 0.33]	<0.001	0.21 [0.10, 0.32]	679.42	<0.0001	94.21%

Note. This table presents summaries of the meta-analyses for Anxiety, General Stress, Depression, PTSD, and all outcomes combined. All Fisher's *z* estimates were attained from multilevel linear models of mixed effects. Each Fisher's *z* was converted to Pearson's *r* for ease of interpretation.