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SYSTEMATIC REVIEW

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Residential exposure to municipal solid waste incinerators and health effects: a systematic review with meta-analysis

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Abstract

Background Municipal solid waste incinerators (MSWIs) are widely used for waste management. However, the health effects of their emissions remain uncertain, needing further investigation and monitoring of the potential risks associated with such exposure. The aim of this study is to update and synthesize evidence on the health effects of residential exposure to MSWIs.

Methods A systematic review with meta-analysis was conducted following PRISMA guidelines. The systematic search in MEDLINE, EMBASE, and Web of Science (April 2025), using specific search strategies, identified observational studies reporting quantitative estimates on the association between long term residential exposure to MSWIs and health outcomes. Study quality was assessed using the Navigation Guide tool. A narrative synthesis was conducted for all outcomes. When possible, a random-effects meta-analysis was performed and Higgins I^2 was used to summarize heterogeneity. For the overall body of evidence, heatmaps were used to visually represent the direction of the associations (positive, negative or lack of association) stratified by study quality.

Results Out of 3,273 records identified, 51 studies were included. The most frequently investigated outcomes were congenital anomalies, pregnancy outcomes, cardiovascular and respiratory diseases, and cancers. The narrative synthesis suggests a weak association for hospitalizations due to cardiovascular and respiratory diseases in high-quality studies and a potential increased risk for non-Hodgkin lymphoma, based on low-quality evidence. The meta-analysis confirms a slight increased risk for respiratory diseases (HR 1.02; 95% CI 0.94–1.11), particularly for COPD (HR 1.08; 95% CI 0.82–1.41) and asthma (HR 1.02; 95% CI 1.00–1.05). Moderate heterogeneity was observed for most outcomes (I^2 = 30%-60%).

Conclusions This review highlights the current uncertainty surrounding the long-term health effects of MSWI exposure. While a slight indication of increased risk emerged for cardiovascular and respiratory hospitalizations, and a weak association with non-Hodgkin's lymphoma was observed, overall evidence remains weak. Methodological limitations, heterogeneity across studies, and low exposure levels complicate risk assessment and comparability. Standardized, high-quality research is needed to clarify these associations and support evidence-based public health decisions and transparent communication with affected communities.

Trial registration The protocol of this review was registered in PROSPERO on 02/06/2024 (CRD42024550168).

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Keywords Municipal solid waste incinerators, Systematic review, Meta-analysis, Cardio-respiratory disease, Non-Hodgkin's lymphoma, Residential exposure

Background

Demographic changes such as population growth and urbanization drive increased resource consumption and waste generation, leading to higher production of municipal solid waste (MSW) [1]. Despite not being classified as hazardous, MSW significantly affects public health, environmental sustainability, and climate change [1]. Improper disposal methods can release harmful chemical compounds, making effective MSW management a critical issue [2]. Incineration allows the reduction of waste volume up to 90% and it has the potential to mitigate groundwater and soil contamination, typically associated with landfills [3]. Additionally, technological development led to the construction of plants capable of recovering energy from the incineration of MSW, known as Waste to Energy plants (WTE) [3]. While waste incineration offers significant advantages for management of waste, it is also associated with the generation of several pollutants [4]. Emissions from incinerators vary significantly based on the type of waste being processed and the conditions of the combustion process, which are influenced by the specific incineration technology [5]. Common emissions include dioxins, furans, heavy metals, sulfur and nitrogen oxides (NO_x), particulate matter (PM), carbon dioxide and acidic gases [5]. These chemicals are known to have a significant toxic potential, capable of interfering with multiple biological pathways. This raises concerns about the potential adverse health effects on populations living nearby [1]. Dioxins and PM are known to exert carcinogenic effects through various biological mechanisms such as genetic mutations, gene silencing, transcriptomic changes and epigenetic modifications [6, 7]. These pollutants can also interfere with cell signalling pathways, leading to transcriptional changes in genes involved in various metabolic processes, including inflammatory and immune responses [7, 8]. Alterations in both inflammatory response and oxidative stress play a role in the pathogenesis of several adverse health outcomes including cardiovascular and respiratory diseases [7, 8]. Additionally, in pregnant women, the inflammatory and oxidative properties of these pollutants can affect normal placental vascularization, potentially resulting in adverse birth outcomes such as preterm birth or abnormal fetal growth [8].

The earlier studies on adverse health effects of residential exposure to MSW incinerators (MSWI) were reports of unusual aggregation of cancer cases in small areas around an incineration plant, suggesting a potential association with the pollutants emitted [9–11]. In recent years, several systematic reviews have been published regarding the health effects on populations living near MSWIs [12–17], with some also addressing health impacts on both nearby residents and exposed workers. The included epidemiological studies employed a range of exposure assessment methods, from simpler proximity-based measures (e.g., distance from the plant) to more advanced geographical approaches using dispersion modeling. These studies suggest small excess risks for certain cancer types, such as lymphomas [12, 15], as well as mental distress and adverse birth outcomes. Associations with cardiorespiratory mortality were also observed, though less consistently. [15, 17]. While several reviews have addressed the health effects of municipal solid waste incinerators, differences remain in methodological approach. In particular, only a few applied a detailed and domain-specific risk of bias assessment framework [12, 13], which is essential for a comprehensive interpretation of findings. Additionally, the application of language restrictions during the selection process may have led to the exclusion of relevant evidence. Only one review provided a meta-analytic estimate of the overall effect, in relation to cancer-related outcomes [12]. Understanding the potential health effects of MSWIs is crucial from a public health perspective. Incinerator plants always generate alarm and concerns among nearby residents, who tend to have heightened perceptions of environmental health risks [18].

This systematic review provides an updated quantitative summary of the health effects of municipal solid waste incinerators on nearby populations. Using a structured methodology, including domain-specific risk of bias assessment with the Navigation Guide tool and meta-analyses where applicable, we aim to provide a comprehensive and rigorous synthesis of the available evidence.

Methods

The study was performed in adherence with PRISMA guidelines [19]. The protocol for this review was registered in PROSPERO (CRD42024550168).

Data sources and searches

We searched up MEDLINE, EMBASE (via OVID) and Web of Science to April 2025, with no restrictions on publication language, to identify studies reporting associations between exposure to incinerators and health outcomes. For each database we developed a comprehensive search strategy incorporating both MeSH terms and text word terms. Details of the MEDLINE search strategy are provided in Additional file 1, Table A1. To identify additional studies, we screened the reference list of relevant systematic reviews. Grey literature was not included in the review, as there are currently no validated tools available to assess its risk of bias.

Inclusion criteria and study selection

We used the population, exposure, comparator, outcome (PECO) framework [20] that guided the entire systematic review process, from the definition of inclusion and exclusion criteria to the identification of keywords for the search strategies. We focused on long-term health effects as waste incinerators contribute to persistent, multimedia environmental contamination and interact with stable health determinants, making long-term impacts particularly relevant from a public health perspective [21]. Given our broad consideration of health outcomes, we also included medium-term effects, including subacute and subchronic exposures, for outcomes like those related to pregnancy [22].

We included observational studies that met the following criteria:

- conducted on residential population;
- provided a quantitative effect estimate for chronic exposure (repeated or continuous exposure over extended periods) to MSWI on long-term health outcomes;
- used any study design;
- addressed any health outcome;
- examined various types of exposure to incinerators or incinerator-related pollutants, including individual doses from biomonitoring, estimated concentrations from dispersion models, and area-based exposure based on residential proximity to the facility.

Studies were excluded for the following reasons:

- exposure to other types of waste;
- absence of an effect estimate;
- occupational exposure;
- focus on short-term health effects;
- health impact assessments, case reports, reviews, conference abstracts or letters, human biomonitoring studies for exposure but not providing quantitative effect estimates.

Search results were imported into the Rayyan program [23] for screening based on inclusion and exclusion criteria. Full texts of relevant publications were reviewed, and study selection was performed by two independent reviewers, with a third reviewer consulted in case of conflicts or doubts.

Data extraction and assessment of risk of bias

To summarize study designs and findings and perform statistical analyses we extracted the following data from each included study: first author, publication year, country, study period, study design, exposure assessment methods, details of pollutants, population characteristics, effect estimates with their confidence intervals, health outcomes, statistical models used and confounders accounted for.

To overcome the limited applicability of traditionally widely used tools such as the Jadad scale [24], Cochrane risk of bias tool (specific to RCT) [25], or JBI Critical Appraisal Checklists (not focused on environmental health) [26], risk of bias was critically assessed using the Navigation Guide tool [27, 28], evaluating domains such as participant recruitment, exposure assessment, confounders and their handling, incomplete outcome data, outcome reporting, and conflicts of interest. Blinding was not considered, as the studies were observational. Following the guidelines provided by the Navigation Guide, which are based on the sufficiency or insufficiency of information regarding the presence or absence of specific biases, each domain was rated as "high", "probably high", as, "low" or "probably low" risk of bias [27]. The final risk of bias tool and criteria used for quality assessment are provided in Additional file 1, Tables A2 and A3.

To ensure a more reliable and transparent quality evaluation, we applied modified criteria specifically tailored to our analysis. These criteria are detailed in Table A2 of the Additional file 1. Data extraction and quality assessment were conducted by two independent reviewers.

Data analysis and synthesis

Following the approach of previous meta-analyses [22, 29], a minimum of three studies per outcome and exposure measure was required to conduct a quantitative summary. A meta-analysis was performed using the Der-Simonian and Laird random-effects method, which accounts for variability both within and between studies. This method assumes that differences in effect sizes reflect both random variation and true differences, with each study's weight determined by the inverse of the total variance, including within-study variance and between-study heterogeneity. Heterogeneity was assessed using Cochran's Q test and the I^2 statistic, with I^2 values of 25%, 50%, and 75% indicating low, moderate, and high heterogeneity, respectively [30].

Studies included in the meta-analysis adopted different exposure categories to quantify the Relative Risk or other effect measure (e.g., Odds Ratio, Hazard Ratio, etc.) associated with the pollutants considered, making it difficult to directly compare their results. To address this, we calculated a continuous risk value for each study and outcome, expressed per unit variation of the pollutant (i.e., 1 ng/m^3 of PM10). First, for each study and outcome, an exposure value was assigned to each exposure category as follows:

$$E_i = (L_i + U_i)$$

where L_i=lower limit of category i, U_i=upper limit of category i.

The lower limit for the first exposure category was always set to 0, while the upper limit for the last exposure category was based on the maximum exposure value reported in the original article. If it was unavailable, the upper limit was estimated by adding ¾ of the width of the previous category's range to the lower limit of the open-ended category of pollutant, as suggested by other authors [31]. The average exposure value (E_i) was then assigned to each category. Then, to obtain an overall study- (and outcome) specific continuous risk estimate, two steps were followed. First, the β coefficients from the original log-transformed relative risk for the category i (ln (RR_i)) were rescaled to a unitary metric (per unit increase in pollutant, e.g. 1 ng/m^3 in PM10) by using the difference between E_i and the average exposure of the reference category (E_1). The categorical effect measures (e.g., Hazard Ratio, Relative Risk, etc.) were transformed into logarithmic values, and logarithmic changes relative to the reference category were calculated for each study. Then, study- (and outcome) specific overall continuous β coefficients were obtained as weighted average with weights given by the number of events in each exposure category (c_i) divided for the sum of events in the categories other than the reference one, as shown in Eq. 1.

$$continuousln\left(RR_{study}\right) = \sum_{i>1} \frac{ln(RR_i)}{\left(\overline{E}_i - \overline{E}_1\right)} \times \frac{c_i}{\sum_{i>1} c_i} \quad (1)$$

where:

E_i is the average exposure for the category i > 1

E_1 is the average exposure for the reference category

$ln(RR_i)$ is the log-transformed Relative Risk for the category i (where $i > 1$) retrieved from the original publication

c_i = events within exposure category $i > 1$

For the study and outcome-specific continuous β coefficients, the standard error (SE) and confidence intervals were then calculated from the variance of each log-transformed relative risk under the assumption of independence of risks between categories (null covariance), as shown in Eq. 2.

$$Var\left[continuousln\left(RR_{study}\right)\right] = \sum\nolimits_{i>1} \frac{Var[ln(RR_i)]}{\left(\overline{E}_i - \overline{E}_1\right)^2} \times \left(\frac{c_i}{\sum_{i>1} c_i}\right)^2 \quad (2)$$

where.

Var [ln (RR_i)] is the variance for each exposure category i (where $i > 1$) retrieved from the original publication

Subgroup analysis was planned if a sufficient number of studies was included in the meta-analysis. Finally, we summarized the entire body of evidence by using heatmaps to visually represent the direction of the associations (positive, negative or lack of association) by study and by outcome, stratified by study quality (grouped in two classes: low quality for studies with high/probably high RoB and high quality for studies with low/probably low RoB). Only significant associations or borderline ones as shown in the original studies were reported as positive/negative. The other findings were classified as no significant associations.

For all other included studies, a narrative synthesis was performed by grouping studies evaluating the same outcomes.

Results

The literature search identified a total of 3282 records, and 82 publications were considered potentially eligible based on their title and abstract. Full-texts were then retrieved and evaluated. Of these, 27 articles were excluded for not meeting the inclusion criteria (see Table A4 in Additional file 1). A total of 51 studies were included, with 5 considered eligible for one or more meta-analyses. The screening process is further described in the PRISMA flow diagram (see Fig. 1).

Characteristics and quality of the included studies

Table A5 in Additional file 1 provides relevant details for each of the included studies. Our search strategy identified 19 studies conducted in Italy, 11 in France, 10 in Asian countries (China, Korea, Taiwan, Japan), 6 in the UK, 4 in the USA and 1 in Brazil. Included studies were cohort studies ($n = 21$), ecological studies ($n = 15$), case–control studies ($n = 10$), cross-sectional design ($n = 5$). Most studies ($n = 33$) included adults as the main population, except for 18, which included pregnant women and newborns in examining neonatal health outcomes.

For exposure assessment, the studies were nearly evenly divided between those that measured exposure using specific incinerator-related pollutants often estimated

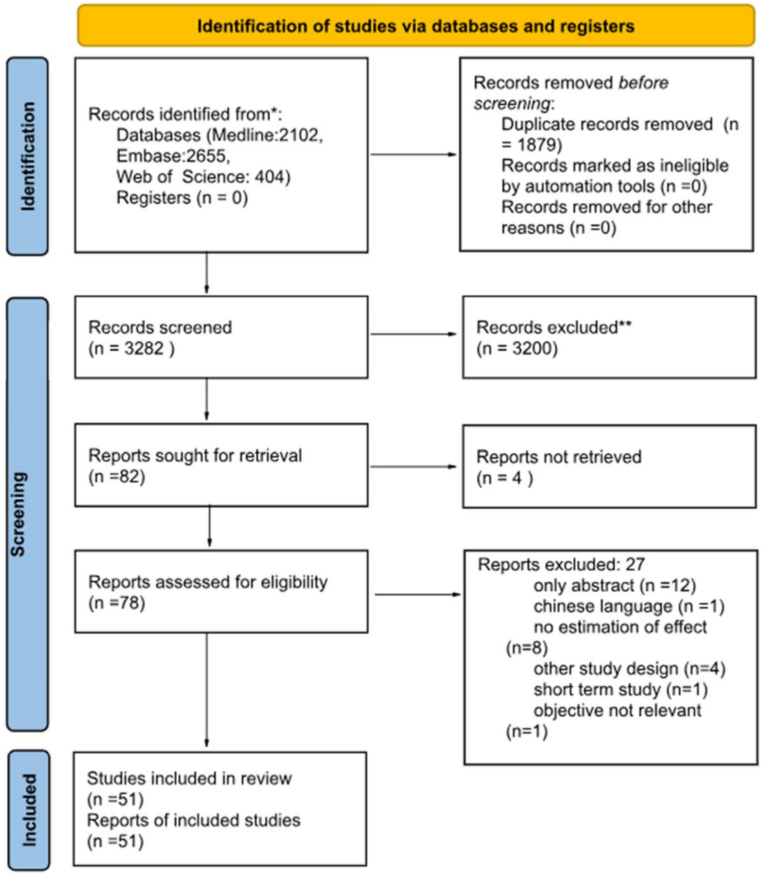

Fig. 1 PRISMA 2020 flow diagram of study selection process

through dispersion models (n =27) or other methods (n =2), and those that used proximity to the MSWI (i.e., distance from the incinerator or area of residence) as an indirect measure of exposure (*n* = 24). Among the 27 studies that implemented a dispersion model to estimate air pollution emissions from the plant, 14 studies focused on dioxins as the tracer pollutant, while 8 studies used PM10. Heavy metals were used as tracers in two studies and NO_x in one study. Finally, two studies assessed exposure using multiple tracer pollutants: one combining both PM2.5 and PCDD/F (polychlorinated dibenzo-p-dioxins and dibenzofurans), and the other examining PM10, NOx, and SO_2 (sulfur dioxide).

Risk of bias

The risk of bias across the studies was mixed. Of the 51 studies, half were evaluated as having a high RoB for exposure assessment domain. The majority of studies were at high (n =27) or probably high (n =5) RoB for confounding while among the remaining low or very low RoB studies there were 13 cohorts, 3 case–control and 3 cross-sectional studies. Incomplete outcome data and outcome reporting bias were a minor concern among the studies with only two studies for each domain classified at high/probably high risk of bias. No studies showed a risk of bias regarding conflicts of interest. Overall, only 13 were classified as having a low or probably low RoB. Among these, 11 were cohort studies and 2 were case–control studies. Table 1 provides a graphical summary of the risk of bias (RoB) assessment for each included study.

Residential exposure to incinerators and health outcomes

The range of adverse health outcomes reviewed across the 51 studies included cardiovascular and respiratory outcomes, cancer, neonatal outcomes, mortality for all cause, and other child outcomes.

Neonatal outcomes

A total of 18 studies examined the association between exposure to incinerators and neonatal outcomes, including studies focused on birth-related outcomes [32–34, 36–38, 40, 42, 47, 50], studies investigating congenital anomalies (CA) [41, 43, 45, 46] and studies considering both [35, 39, 49].

Table 1 Risk of bias evaluation of the included studies for each domain of Navigation Guide tool

Study	Outcomes	Exposure assessment	Confounders	Incomplete outcome data	Outcome reporting	Conflict of interests
Hao et al., 2022 [32]	BIRTH	H	PH	L	L	L
Ghosh et al., 2019 [33]	BIRTH	PL	PL	PL	L	L
Freni-Sterrantino et al., 2019 [34]	BIRTH	H	PH	L	L	L
Vinceti et al., 2018 [35]	BIRTH; CA	L	H	L	L	PL
Santoro et al., 2016 [36]	BIRTH	L	PL	L	L	L
Candela et al., 2015 [37]	BIRTH	L	PL	L	L	L
Candela et al., 2013 [38]	BIRTH	PL	PL	L	L	L
Vinceti et al., 2008 [39]	BIRTH; CA	L	H	L	L	PL
Tango et al., 2004 [40]	BIRTH	H	H	L	L	PL
Dummer et al., 2003 [41]	BIRTH; CA	H	H	L	L	L
Williams et al., 1992 [42]	BIRTH	H	H	L	L	PL
Parkes et al., 2020 [43]	CA	PL	PL	L	L	L
Cordier et al., 2010 [44]	CA	L	L	L	L	L
Vinceti et al., 2009 [45]	CA	L	H	L	L	PL
Cordier et al., 2004 [46]	CA	PL	PH	L	H	PL
Gandini et al., 2025 [47]	CVD; RESP; BIRTH;	L	PL	L	L	L
Zhang et al., 2024 [48]	RESP	H	L	L	L	L
Piccinelli et al., 2022 [49]	CVD; RESP; CANCER; BIRTH; CA; OTHER	L	PL	L	L	L
Chellini et al., 2020 [50]	CVD; RESP; CANCER; BIRTH; OTHER	L	H	L	L	L
Romanelli et al., 2019 [51]	CVD; RESP; CANCER; OTHER	L	PL	L	L	L
Fonte et al., 2017 [52]	CVD; RESP	L	H	L	L	L
Minichilli et al., 2016 [53]	CVD; RESP; CANCER; OTHER	L	PL	L	L	L
Golini et al., 2014 [54]	CVD; RESP; OTHER; CHILD	L	PL	L	L	L
Ranzi et al., 2011 [55]	CVD; RESP; CANCER; OTHER	L	PL	L	L	L
Fukuda et al., 2003 [56]	CVD; CANCER	H	H	L	L	PL
Kim et al., 2022 [57]	RESP; CHILD	H	PH	L	L	L
Bae et al., 2020 [58]	RESP; CHILD	H	H	L	L	L
Mohan et al., 2000 [59]	RESP	H	PL	L	L	PL
Praud et al., 2025 [60]	CANCER	L	PL	L	L	L
Fisher et al., 2024 [61]	CANCER	PH	PL	L	L	L
VoPham et al., 2020 [62]	CANCER	H	PL	L	L	L
Barjoan et al., 2020 [63]	CANCER	PL	H	L	L	L
Viel et al., 2011 [64]	CANCER	L	H	L	L	L
Federico et al., 2010 [65]	CANCER; CHILD	H	H	L	L	PL
Gouveia & Ruscitto do Prado, 2010 [66]	CANCER; CHILD	H	H	L	L	PL
Goria et al., 2009 [67]	CANCER	PL	H	L	H	L
Viel et al., 2008a [68]	CANCER	PL	PH	L	L	L
Viel et al., 2008b [69]	CANCER	PL	H	L	L	L
Zambon et al., 2007 [70]	CANCER	L	H	H	L	L
Bianchi et al., 2007 [71]	CANCER	H	H	L	L	L
Biggeri & Cattelan, 2006 [72]	CANCER	H	H	L	L	L
Floret et al., 2004 [73]	CANCER	PL	H	L	L	PL
Floret et al., 2003 [74]	CANCER	PL	H	L	L	PL
Viel et al., 2000 [11]	CANCER	H	H	L	L	PL
Elliott et al., 1996 [10]	CANCER	H	H	L	L	PL
Biggeri et al., 1996 [9]	CANCER	H	PL	PH	L	PL
Ji et al., 2022 [75]	OTHER; CHILD	H	H	L	L	L
Lung et al., 2020 [76]	CHILD	H	H	L	L	L
Lung et al., 2013 [77]	CHILD	H	H	L	L	L
Miyake et al., 2005 [78]	CHILD	H	H	L	L	PL

BIRTH birth-related outcomes, *CA* congenital anomalies, *CARDIO* cardiovascular diseases, *RESP* respiratory diseases, *CANCER* cancer outcomes, *OTHER* other health outcomes, *CHILD* children's health, *H* high risk of bias, *PH* probably high risk of bias, *L* Low risk of bias, *PL* probably low risk of bias

Birth-related outcomes

Thirteen studies investigated the association between birth-related outcomes and exposure to dioxins, PM10, or proximity to incineration plants [32–40, 42, 47, 49, 50]. A closer examination, as provided in the heatmap available in Additional file 2, reveals limited and inconsistent evidence linking MSWIs exposure to birth-related outcomes, with most studies reporting lack of association with preterm births, low birth weight, spontaneous abortions, small-for-gestational-age infants and miscarriages linked to PM10 or dioxin exposure.

Significant associations were observed in only a few studies of low quality for outcomes such as small for gestational age [32], infant deaths [40] and sex ratio [42], and of high quality for preterm [38] and miscarriages [37]. One case–control study examined the distribution of preterm births in the Italian municipalities of Pietrasanta and Camaiore, exposed to emissions from two MSWIs [50]. The study found a statistically significant lower rate of preterm births in these municipalities compared to the regional average [50]. However, a non-significant higher rate of preterm births was observed in areas highly exposed to emissions from the plants [50]. A birth cohort study conducted in China investigated the association between maternal residence within 10 km from plants and adverse birth outcomes. No significant association was observed for preterm birth [32]. Similarly, an English study also found no significant association between proximity to MSWIs or exposure to their emissions and adverse birth outcomes [33]. An increased risk ok preterm birth not statistically significant was found in the exposed area in an Italian cohort study on Turin WTE plant [47]. In a study by Chellini et al., 2020 [50], the impact of modelled PM2.5 and PCDD/F exposure on low birth weight was examined in two municipalities near MSWIs, but no increased risk was found in areas with higher exposure. Similarly, an ecological study by Tango et al. 2004 [40] assessing the risk of adverse reproductive outcomes related to proximity to MSWIs found no significant associations with low birth weight (< 2500 g) or very low birth weight (< 1500 g). Three other Italian studies [36, 47, 49] also reported no significant results for low birth weight. Additionally, an English study found no association between proximity or exposure to MSWIs and term birth weight [33].

A cohort study reported a significant association between small for gestational age (SGA) and maternal residence within 10 km from MSWIs, with an additive interaction between MSWIs exposure and mothers' low BMI on the risk of SGA [32]. No effect on SGA was observed in three Italian studies [36, 38, 47], as well as a study conducted in the UK [33].

Regarding miscarriages, an Italian cohort study highlighted an association between increased maternal exposure to modelled PM10 and a higher risk of spontaneous abortion [37]. Two additional Italian studies examined the effects of the Modena MSWI on adverse reproductive outcomes [35, 39]. The earlier analysis reported no increase of miscarriage [39], while a more recent study suggested a potential dose–response relationship with dioxin exposure categories. However, the observed increased risk was not statistically significant [35]. No significant results were reported for miscarriage in an Italian cohort study focusing on the WTE plant of Turin [47].

Studies on the impact of MSWIs on perinatal outcomes report no clear associations. In Japan [40], no significant link between maternal residence within 10 km of an incinerator and neonatal or spontaneous fetal deaths was found, though a decline in infant mortality risk with increasing distance was noted, particularly for deaths due to congenital malformations. In the UK, Freni-Sterrantino et al., 2019 [34] found no significant differences in infant mortality trends near MSWIs compared to control areas, while Ghosh et al., 2019 [33] reported no increase in stillbirths, neonatal, postnatal, or infant mortality. Similarly, Dummer et al., 2003 [41] found no significant association between MSWI proximity and stillbirth or neonatal deaths.

Regarding sex ratio, Williams et al., 1992 [42] reported a significant excess of female births in areas near two MSWIs in central Scotland. However, Freni-Sterrantino et al., 2019 [34] and Gosh et al., 2019 [33] found no significant changes in sex ratio trends in areas close to MSWIs compared to control regions. Similarly, no significant association between changes in sex ratio and exposure to WTE plant of Turin was observed [47].

For multiple births, Piccinelli et al., 2022 [49] reported no significant association between exposure to a MSWI and twin births in Italy. Similar findings were observed in two other Italian studies [38, 47] and a UK study [33], where no association was found between an increase in multiple births and MSWI exposure.

In summary, while a few studies reported statistically significant associations between MSWI exposure and birth-related outcomes, the majority of the evidence points to null results. Thus, narrative synthesis suggests lack of consistent and robust evidence supporting a link between MSWIs and adverse reproductive or birth outcomes.

Congenital anomalies

Heat maps for congenital anomalies (Additional file 3 and 4) showed an overall lack of association, mostly from low quality studies with MSWIs exposure measured by proximity, or by PM10 or dioxin exposure. Only three low quality studies [41, 43, 46] and one high quality study [44] suggest significant association on specific malformations, such as neural, heart, urinary tract, genital malformations and facial cleft.

Three studies [41, 44, 46] found significant associations between proximity to MSWIs and specific congenital anomalies. A UK study by Dummer et al., 2003 [41] showed an increased risk of lethal congenital anomalies, including neural tube defects, spina bifida, and heart defects, with proximity to MSWIs. A French case–control study [44] found a significant association between early-pregnancy exposure to dioxins and urinary tract birth defects. Additionally, an ecological study in the same area [46] observed associations between MSWI exposure and facial clefts, renal dysplasia, and a dose–response relationship for obstructive uropathies, but no increased risk for other anomalies. Another UK study [43] reported increased risks for genital defects, hypospadias, and heart defects when proximity to an MSWI was used as the exposure measure, but no significant associations were found when PM10 levels were used. In contrast, four Italian studies [35, 39, 45, 49] found no increased risk of congenital anomalies associated with higher dioxin or PM10 concentrations.

In summary, although a few studies reported significant associations between MSWI exposure and specific congenital anomalies, most studies found no such associations. The narrative synthesis suggests an overall lack of clear evidence linking MSWIs to congenital anomalies, with positive findings limited to isolated outcomes and not supported by the overall body of evidence.

Cancer

Twenty-one studies focused on cancer-related outcomes [9–11, 49, 51, 53, 55, 56, 62–74]. The reviewed studies addressed lymphohematopoietic tumors and solid tumors in nearly equal proportions.

All cancers

Heat maps for all cancer sites (Additional file 5, 6 and 7) showed an overall lack of association for eight studies evaluating the effects of exposure to MSWIs on morbidity and mortality from all-cancer sites [10, 49, 55, 56, 63, 65–67]. Only for two studies, one of low [67] and one of high quality [55], a potential higher risk was observed only in women. The remaining six studies reported no significant associations with all-cancer mortality, hospitalization, or incidence [10, 49, 56, 63, 65, 66].

In an Italian cohort, increased all-cancer mortality was associated with exposure to modelled heavy metal concentrations in the highest exposure class among women, but not among men [55]. Similarly, an ecological study in France found a positive association between all-cancer risk and dioxin exposure from 16 MSWIs for women but not for men [67]. In contrast, a Japanese study found no statistically significant association between cancer mortality and dioxin exposure at municipal level in either sex [56]. An ecological study in São Paulo, Brazil, found no association between increased cancer mortality risk and proximity to MSWIs, using distance as an exposure proxy [66]. Similarly, an Italian study did not find a significant increase in cancer hospitalization or mortality risk for individuals exposed to higher modelled PM10 concentrations [49]. An earlier ecological study in Great Britain has found increased cancer incidence (observed and expected cases ratio) near 72 MSWIs, with the risk declining as distance from the incinerators increased [10]. However, further analysis revealed that this excess of cases was already present in the area before the incinerators became operational, suggesting that the findings might be attributable to residual confounding [10]. An ecological study in Nice, France, reported no significant increase in cancer incidence near the MSWI during 2005–2014 [63]. Likewise, an ecological study in an area defined by a 5 km radius around the MSWI of Modena (Italy) found no increase in cancer incidence associated with closer proximity to the plant [65].

Tumors of the lymphohematopoietic system

Five studies examined the relationship between MSWIs exposure and the entire group of tumors of the lymphohematopoietic system [10, 49, 51, 55, 63]. One study observed increased mortality [51] (in red in the heat maps of Additional file 5, 6 and 7).

An Italian study reported an excess mortality risk (HR $=1.79$; 95% CI 1.03–3.12), as well as a + 23% HR trend among men highly exposed to NO_x from the Pisa MSWI while no significant excess was observed for hospitalization [51]. Another study identified an increased mortality risk for lymphohematopoietic cancers in women exposed to high heavy metals concentrations during the period 1990–2003 but no significant results were observed for incidence of lymphohematopoietic cancers and for both mortality and incidence of myeloma [55].

Non-Hodgkin's lymphoma

Sixteen studies investigated the association between exposure to MSWIs emissions and morbidity or mortality from Non-Hodgkin's lymphoma (NHL) [10, 11, 49–51, 53, 55, 61, 63–66, 69, 71, 72, 74]. Heat maps (Additional file 5, 6 and 7) suggests some evidence of association (in red colour) in nine out of the 15 studies, all of low quality [11, 50, 51, 63, 64, 69, 71, 72, 74] (five associations in women, one in men and five in total population).

A series of studies evaluated the risk of NHL related to emissions from MSWIs. In Doubs, France, a cluster of NHL cases was identified near the Besançon MSWI in the period 1980–1995 [11]. Subsequent research found a 2.3-fold increased risk of NHL in areas with higher modelled dioxin exposure [74]. Further analysis linked high serum levels of dioxins, furans, and PCBs (polychlorinated biphenyl) to NHL risk [64]. Another French study across four departments (Isère, Bas-Rhin, Haut-Rhin, Tarn) confirmed increased NHL risk, especially in women, in areas with high dioxin exposure (RR: 1.178; 95% CI: 1.013–1.369) [69]. In Nice, an association between MSWI emissions and specific NHL subtypes was observed in men during the period 2005–2009 when the plant was operational [63]. In Italy, a case–control study linked PCDD/F exposure to NHL [50]. Another Italian study found no significant associations with PM10 [49]. One cohort study reported no significant association between increased risk of NHL incidence and residential proximity to MSWIs in the United States [61]. Broader ecological studies in Italy and the UK also reported no consistent NHL risk linked to proximity to incinerators [10, 65]. Overall, findings suggest localized risks in specific contexts but no systematic evidence of increased NHL incidence. An Italian study analyzed NHL mortality in municipalities of the Tuscany region where a MSWI was operational between 1970–1989, identifying a significant excess mortality among males from 1981 to 2001 [72]. A subsequent study of 25 Italian municipalities with active MSWIs corroborated these findings, showing increased male NHL mortality but no significant increase among female [71]. Similarly, an increased trend of NHL mortality (+ 29%) and a trend close to significance for NHL morbidity (+ 21%) was observed among men of an Italian cohort exposed to elevated concentrations of NO_x emitted from Pisa MSWI [51]. Conversely, a study of hospitalization and mortality in a cohort exposed to PM10 from the San Zeno MSWI (2001–2010) reported no significant risk for NHL outcomes [53], though the plant was linked to adverse reproductive outcomes [36]. An analysis of mortality linked to heavy metals from the Forlì MSWI also found no significant NHL associations [55]. Finally, an ecological study within 7 km of the São Paulo MSWI showed no association between NHL mortality and plant proximity [66].

Leukemia

Eight studies have examined the association between exposure to MSWIs and leukemia [10, 49–51, 53, 55, 65, 66], with only two low quality studies providing evidence of association in total population [50] and in women [63]. The first study was a case–control study in Italy (Pietrasanta and Camaiore incinerators) which identified a significant association between high PCDD/F exposure from two incinerators and leukemia cases (OR: 4.12; 95% CI: 1.82–9.32), but no link with PM2.5 [50]. Barjoan et al., 2020 [63] observed a significant increase in the incidence of acute myeloid leukemia in both sexes near the Nice incinerator during 2005–2009, prior to the facility's upgrade. This increase was not sustained following the plant's renewal [63]. Two studies observed non-significant increase in leukemia mortality risk among exposed individuals [51, 53], and one study identified an increasing trend in leukemia hospitalization among exposed men [51]. Of these, one is an Italian cohort, where non-significant excess mortality risk was observed across medium (HR: 2.09%; 95% CI: 0.93–4.69) and high (HR: 1.64; 95% CI: 0.53–5.13) PM10 exposure categories [53]. The other is an Italian study in the area surrounding the MSWI of Pisa (2001–2014) which observed increasing mortality risk for leukemia in both exposed men (+ 26%) and women (+ 39%), along with a 21% rise in hospitalization risk for men [51]. A statistically significant increase in incidence of leukemia was observed in an ecological study evaluating association between distance from the MSWI of Modena (Italy) and cancer incidence, among females and combined genders residing in the area within 2 and 3.5 km from MSWI [65]. However, no such increase was reported in other bands defined as 0–2 km and 3.5–5 km from the incinerator, suggesting that the increase observed in the second band was not to be attributed to proximity to the incinerator plant [65]. Furthermore, an additional analysis of incidence of childhood cancer yielded no significant results for leukemia [65]. Similarly, no significant association between increasing proximity to a MSWI and increased leukemia mortality in children was observed in an ecological study of São Paulo MSWI [66]. No significant results were observed in two Italian cohorts [49, 55] and in an ecological study (72 MSWIs in Great Britain [10]).

Other tumors of the lymphohematopoietic system

One Italian study found no significant results for incidence of lymphohematopoietic tumors and for both mortality and incidence of myeloma [55]. In France, elevated incidences of myelodysplastic syndromes, and myeloma were observed among women near the Nice MSWI before its upgrade (2005–2009) [63]. Men showed increased multiple myeloma incidence. Following the plant's renewal (2010–2014), persistent significant excess was noted only for multiple myeloma in men, suggesting reduced emissions could mitigate risks [63]. An ecological study evaluating association between residential proximity to 72 MSWIs and cancer incidence found no significant increase in multiple myeloma [10]. Similarly, no significant excess risk for hospitalization or incidence of multiple myeloma and immunoproliferative tumors was found in an Italian cohort highly exposed to Valmadrera incinerator's emissions [49].

Lung and laryngeal cancer

Ten studies have investigated the association between MSWIs exposure and lung and laryngeal cancers [9, 10, 49, 50, 55, 56, 63, 65–67] (see heat maps in Additional file 5, 6 and 7). Of these, one low quality study showed increased lung cancer mortality associated with proximity to a MSWI [9], and two low quality studies reported significant increases in lung cancer incidence [50, 63] with one also noting an increase in larynx cancer incidence [50]. Two studies were case–control [9, 50]. A case–control study in Pietrasanta found elevated risks for lung (OR: 1.5; 95% CI: 1.1–2.0) and larynx cancer (OR: 3.2; 95% CI: 1.5–67) associated with high PCDD/F exposure, but no link with PM2.5 [50]. The other case–control study carried out in Trieste, Italy, reported a 6.7-fold increase in lung cancer risk among residents living near a MSW incinerator, decreasing with distance [9]. These findings are consistent with those of a French study evaluating cancer incidence in the surroundings of Nice's incinerator plant during the period 2005–2014 [63]. Results reported an elevated incidence of lung cancer during the period 2005–2009 among men exposed to MSWI emissions. Following the plant's upgrade, a significant excess of lung cancer persisted. In the same study no association with larynx cancer was observed [63]. In other studies, three from Italy [49, 55, 65], one from Great Britain [10], one from Japan [56] and one from France [67] no significant association between lung or laryngeal cancers were found. Only in the Great Britain study, an ecological analysis of 72 MSWIs, an increased incidence of lung cancer near incinerators was found, though a post-hoc analysis attributed this to residual confounding while no significant results were found for laryngeal or nasopharyngeal cancers [10].

Sarcoma

For sarcoma, nine studies investigated its association with residential exposure to MSWIs [10, 11, 50, 51, 55, 63, 65, 70, 73]. Of these, three observed a statistically significant association between MSWIs and increased sarcoma risk [11, 63, 70].

The first was a case–control study evaluating risk of all-sites sarcoma and specific subtypes in the province of Venice, Italy where several MSWIs are located [70] . A significant excess risk of all-sites sarcoma was observed, particularly among women highly exposed to dioxins emitted by the plants. Additionally, excess risk for sarcomas of the connective and other soft tissues was found in the exposed population [70]. However, a non-significant excess risk for visceral sarcomas was observed, and no significant associations were found for skin or peritoneal sarcomas [70]. The study also highlighted that the increased risk of sarcoma was associated with higher levels and longer durations of exposure to the incinerator emissions [70]. Findings of an ecological French study near the Besançon incinerator, characterized by a high level of dioxins emission, identified a disease cluster in the area, but a subsequent case–control study did not find a higher risk of soft tissue sarcoma in individuals with high dioxin exposure [11, 73]. A French study evaluating cancer incidence in the surroundings of Nice's incinerator plant reported an elevated incidence of STS during the period 2005–2009 among men exposed to MSWI emissions [63]. Following the plant's upgrade, no significant excess was observed, indicating a potential impact of reduced emissions on cancers with shorter latency periods, such as STS [63]. Other studies from Italy, one case–control [50], one ecological [65] and two cohorts [51, 55] observed no significant association with sarcoma mortality or hospitalizations. Another ecological study from UK found no significant increase in soft tissue sarcoma risk related to MSWIs proximity [10]. Further analysis by Federico et al., 2010 [65] also found no significant link between MSWI exposure and childhood soft tissue sarcoma.

Breast cancer

Six studies have explored the association between exposure to MSWIs and breast cancer risk [55, 60, 62, 63, 67, 68] (see heat maps in Additional file 5, 6 and 7). Of these studies, three low quality investigations observed a significant association between breast cancer risk and MSWIs [55, 62, 67]. The first, a French ecological study covering 16 MSWIs in 4 departments, found a significant linear positive association between exposure to emissions and breast cancer risk [67]. The second study was a US nationwide cohort study of 116,429 female nurses in the period 1989–2013, showing a significant excess risk of invasive breast cancer for women living within 5 km (HR: 1.25; 95% CI: 1.04, 1.52) and 10 km (HR: 1.15; 95% CI: 1.03, 1.28) from an incinerator plant [62], with higher risk associated with longer durations of residence (> 6 years) and higher levels of emissions from incinerator plants located within 3 km, 5 km and 10 km [62]. Similarly, an Italian cohort study observed a notable increased gradient in breast cancer mortality for women highly exposed to heavy metals emitted from the MSWI of Forlì, yielding a rate ratio of 2.00 (95% CI: 1.00—3.99) [55]. An association close to the limit of significance was observed between dioxin exposure and increased risk of breast cancer in a French case–control study nested in a national cohort

[60]. In contrast, another French study, evaluating cancer incidence near Nice's incinerator, observed no significant results for breast cancer [63] A case–control study examining the association between dioxin concentrations and invasive breast cancer risk found no significant results for women under 60 with a slight reduction in risk for women over 60 in high-exposure areas [68]. The authors suggested that these findings could be due to residual confounding factors [68].

Liver cancer

A total of 8 studies examined the relation between pollutants emitted from MSWIs and liver cancer [10, 49–51, 55, 63, 65, 67]. Among these studies, one study found a non-significant increased liver cancer mortality risk among exposed women [55] (high quality) and one study reported a significant excess of liver cancer cases [50] (low quality). The first study was an Italian cohort observing an increasing gradient of liver cancer mortality among women exposed to high levels of heavy metals emitted from the Forlì incinerator [55]. The second study was an Italian case–control study which observed a significant excess of liver cancer cases associated to high exposure levels to PM2.5 (OR: 2.30; 95% CI: 1.46–3.62) and PCDD/F (OR: 4.45; 95% CI: 2.85–6.97) from MSWI emissions [50]. Similarly, a retrospective cohort study found a significant excess in liver and bile duct cancer incidence and hospitalization among individuals exposed to PM10 from the Valmadrera incinerator [49]. Authors suggested that these results could have been influenced by the high prevalence of hepatitis C virus in the area under study [49]. Furthermore, an ecological study investigating cancer incidence in areas surrounding 72 MSWIs in Great Britain also noted an excess of liver cancer cases associated with proximity to incinerator plants [10]. Authors suggested that these findings could be attributable to misdiagnosis of primary liver cancer cases [10]. In contrast, other studies reported no significant associations, including ecological investigations near incinerators in France [63, 67], São Paulo [66], and Modena [65]. Non-significant results were also reported for both mortality and morbidity in a cohort in Italy [51].

Stomach and colon-rectal cancer

A total of 6 studies included stomach and colon-rectal cancer within the investigated outcomes [10, 49, 51, 55, 56, 65] (see heat map in Additional file 5, 6 and 7). Of this, one study described a significant excess risk of stomach cancer mortality and colon cancer incidence among women exposed to heavy metals emitted from the plant, and increased colorectal cancer mortality in men, though no significant results were found for colorectal cancer incidence [55] (high quality). An ecological study in Great Britain found increased stomach and colon-rectal cancer incidence [10]. Post-hoc analysis identified an effect of residual confounding in the band defined as 0–3 km from MSWI [10] (low quality). No significant excess risk of stomach and colon-rectal cancer was found in other Italian [49, 51]- high quality, [65]—low quality and Japanese [56]—low quality studies.

Other solid tumors

Four studies evaluated whether residential exposure to MSWIs could play a role in the onset of other types of solid tumors [10, 49, 55, 63]. Of these, one study identified an excess risk of brain and other central nervous system cancer among exposed individuals [49] and one described an increased gradient of bladder cancer mortality among women [55]. One Italian cohort study reported an increased risk of first hospitalization for cancers of the brain and central nervous system and pleural cancer among women exposed to high PM10 concentrations near the Valmadrera incinerator [49]. Additionally, a significant increase in mortality risk from pleural cancer was observed among exposed men in the same cohort [49]. No significant results were observed for the central nervous system cancers in an Italian cohort study assessing mortality and morbidity among residents in the area surrounding Forlì MSWI [55]. Regarding bladder cancer, a cohort study identified an increased mortality gradient in highly exposed women [55]. No significant association for prostate cancer were observed [55]. No significant associations for bladder cancer or pleural mesothelioma were observed in an ecological study analyzing emissions from the Nice incinerator [63] or in a study investigating cancer incidence around 72 MSW incinerators in Great Britain [10].

In summary, although some studies reported associations between MSWI exposure and specific cancer types, most found no significant results. Limited evidence of increased risk was observed for lymphohematopoietic tumors, particularly NHL. For other cancers, such as lung, liver, and sarcoma, only isolated associations were reported. Overall, the narrative synthesis suggests a lack of consistent evidence linking MSWI exposure to increased cancer risk.

Cardiovascular and respiratory outcomes

Thirteen studies evaluated the association between exposure to f MSW incinerators and cardiovascular and respiratory outcomes [49–59, 78, 79] (see heat maps in Additional file 8 and 9). Most of the evidence comes from high-quality studies, with some reporting significant associations (indicated in red on the heat maps) or borderline associations (marked with an asterisk) between MSWI exposure and specific health conditions. Conversely, two high quality studies did not provide evidence of association [47, 74].

Cardiovascular diseases

Of the studies on total cardiovascular causes, three high quality cohorts [51, 53, 55] and one low quality study [50] found a significant association with exposure to MSWIs (see heat map in Additional file data 8).

An Italian cohort study showed a significant excess mortality from cardiovascular diseases among women exposed to emissions from the Forlì MSWI [55]. Another cohort study in Pisa, Italy, identified a significant increase in mortality risk from cardiovascular diseases among men exposed to modelled concentrations of NO_x emissions from the MSWI (HR: 1.21%; CI 95%: 1.05–1.39%) [51]. Similarly, an Italian cohort study examining the San Zeno incinerator found a 15% increasing trend in cardiovascular mortality risk among men highly exposed to modelled PM10 concentrations, with an observed 20% excess risk (HR:1.20; CI 95% 0.89–1.61) [53]. Another study focusing on two Italian municipalities (Pietrasanta and Camaiore), found an excess of mortality from cardiovascular diseases among both genders compared to regional data [50]. Additionally, an excess in hospitalization from cardiovascular diseases was observed among men in these areas, while a decrease was observed in women [50]. Conversely, a study on the Busto Arsizio incinerator, employing both case–control and cohort designs, found no significant association between exposure and hospitalization due to cardiovascular diseases [52]. No significant results were observed in a cohort study focusing on the WTE plant of Turin, Italy [47].

Ischemic heart diseases natural

Seven studies investigated ischemic heart disease (IHD) in relation to exposure to MSWIs [47, 49, 51, 53–56], with three focusing on acute myocardial infarction (AMI) [49, 51, 55] (see heat map in Additional file 8).

Romanelli et al., 2019 [51] observed an elevated mortality risk, approaching statistical significance for all ischemic heart disease causes (HR 1.24,95% CI 0.99;1.55) as well as for AMI mortality (HR: 1.38; 95% CI: 0.97;1.98) among men. One Italian study described a significant increased risk for hospitalization due to ischemic heart disease in the population exposed to emissions from the WTE plant of Turin [47].Similarly, Minichilli et al., 2016 [53] reported a non-significant increased mortality risk among men residing in the area surrounding San Zeno incinerator (HR1.43; 95% CI 0.87;2.36) and a 17% increasing trend for both genders combined [53]. Fukuda et al., 2003 [56] found no significant associations with IHD mortality after adjusting for socioeconomic factors.

Studies examining emissions from the Valmadrera [49] and Forlì [55] incinerators reported no significant excess risk nor for ischemic heart disease nor for AMI hospitalization.

Cerebrovascular diseases

Four studies examined the relationship between exposure to MSWIs and cerebrovascular diseases, consistently reporting no significant associations [47, 49, 51, 54]. Golini et al., 2014 [54] found no excess risk of hospitalization for cerebrovascular diseases among residents near the WTE plants of Colleferro and San Vittore during the period 1996–2008 [54]. Similarly, Romanelli et al., 2019 [51] observed no significant risk for cerebrovascular diseases in terms of both hospitalization and mortality among individuals exposed to emissions from the Pisa incinerator. Piccinelli et al., 2022 [49] also reported no significant excess risk of hospitalization or mortality from cerebrovascular diseases for individuals exposed to modelled PM10 concentrations near the Valmadrera incinerator. No significant results were observed for hospitalization from cerebrovascular diseases in a cohort study focusing on Turin WTE plant [47].

Other cardiovascular conditions

Three studies evaluated the relation between MSWIs emissions and other cardiac outcomes, all of them identifying significant associations [47, 52, 55]. Ranzi et al., 2011 [55] (high quality), reported a significant increase in hospital admissions for chronic heart failure among men exposed to modelled heavy metals concentrations emitted from Forlì incinerator. Another high quality study [47] observed a significant increased risk of chronic heart failure hospitalization related to exposure to the WTE plant of Turin. The study also observed an association close to the limit of significance for cardiac disease [47]. Comparable results were shown in an Italian study (low quality), through a combination of case–control and cohort approaches, where a significant association was observed between exposure to MSWI-related NOx and SO2 and hospitalization due to specific cardiovascular causes including heart failure, cardiac arrhythmias, embolism and arterial thrombosis, acute myocardial infarction, cardiovascular symptoms, other forms of chronic ischemic heart disease and conduction disorders [52].

Respiratory diseases

Seven studies investigated whether exposure to MSWIs could represent a risk factor for total respiratory diseases, yielding mixed results [47, 49, 50, 52–55] (see heat map in Additional file 9). The heat map suggests a lack of consistency, with only limited to localized significant associations mostly from high quality studies (in red in the heat map).

Four studies identified associations between MSWIs residential exposure and total respiratory diseases, of which three were of high quality [47, 53, 55] and one of low quality [50] (in red colour in the heat map Additional file 9). A significant increase in mortality from respiratory diseases among men exposed to modelled heavy metal concentrations emitted by the Forlì incinerator was shown in a study by Ranzi et al., 2011 [55]. Similarly, Minichilli et al., 2016 [53] observed an increasing trend in mortality due to respiratory diseases among women exposed to emissions from the San Zeno incinerator. A cohort study focusing on Turin WTE plant reported a significant increased risk of respiratory diseases hospitalization among individuals most exposed to the plant's emissions [47]. Chellini et al., 2020 [50] found higher hospitalization rates for respiratory diseases in two municipalities near MSWI plants (Pietrasanta and Camaiore) compared to regional data, though mortality rates remained comparable. However, Fonte et al., 2017 [52], employing both case–control and cohort designs, found no significant association between exposure to emissions from the Busto Arsizio incinerator and hospitalizations due to respiratory diseases.

Chronic pulmonary disease

Six studies examined the effects of exposure to pollutants emitted from MSWIs and chronic pulmonary diseases [47, 49, 51, 53–55]. Two high quality studies found a significant association with MSWIs [49, 54], only in males.

Other four studies did not support a significant association between MSWIs emissions and COPD [47, 51, 53, 55].

Asthma

Seven studies investigated the association between exposure to MSWIs and asthma [49, 53–55, 57, 58, 78].

One Italian cohort study provided evidence for a significant association between MSWIs and asthma admissions (high quality) [49]. Miyake et al., 2005 [78] (low quality) conducted a cross-sectional study in Japan, examining children's symptoms in relation to the proximity of their school to nearby MSWIs. The study found a significant positive association between shorter distances to the incinerators and higher prevalence of wheeze [78]. Bae et al., 2020 [58] conducted an ecological study in Seoul, where 6 MSWIs are located, and found significant excess risk of asthma-related hospital admissions in individuals living within 2 km of the plants (RR: 1.13%; 95% CI: 1.10–1.17) (low quality). Vulnerable groups, including children aged < 15 years (RR: 1.12%; 95% CI: 1.08–1.17) and individuals over 65 years (RR:1.18%; 95% CI: 1.10–1.27) being particularly affected [58]. In contrast, an Italian cohort and a Korean cross-sectional study showed no significant excess of asthma-related hospitalization or prevalence [55, 57].

Acute respiratory diseases

Four studies investigated the association between MSWIs emissions and acute respiratory diseases [47, 51, 53, 55], with mixed results.

Three studies suggested a potential link. Romanelli et al., 2019 [51] reported an excess risk of mortality from acute respiratory diseases among women highly exposed to MSWI-related NO_x, although no significant association was found for hospitalization. Similarly, Minichilli et al., 2016 [53] observed a rising trend in mortality risk from acute respiratory diseases among women exposed to elevated PM10 concentrations from the San Zeno incinerator. Gandini et al., 2025 [47] observed an increased risk close to the limit of significance for hospitalization from acute respiratory diseases in individuals most exposed to emission from Turin WTE plant. Conversely, Ranzi et al., 2011 [55] found no significant excess risk for either mortality or hospitalization from acute respiratory diseases in a population exposed to heavy metals emitted by the Forlì MSW incinerator.

Two studies investigated the potential link between MSW incinerator emissions and respiratory infections, including viral and bacterial infections [49, 54]. Of these, one study observed significant findings [49] (red colour in the heat map), with an excess risk of mortality from viral and bacterial infections among women highly exposed to modelled PM10 concentrations. Conversely, Golini et al., [54] found no significant excess risk for mortality or hospitalization due to acute respiratory infections in individuals exposed to high levels of MSWI-related PM10. Furthermore, no associations were observed for respiratory outcomes in children under 14 years of age [54].

Other respiratory conditions

Six studies investigated the relationship between MSWIs emissions and a variety of other respiratory conditions [48, 52, 57, 59, 78, 79]. Among these, one study found significant associations with allergic rhinitis [57] and one with respiratory symptoms [48] (red colour in the heat map in Additional file 9).

Kim et al., 2022 [57] observed a near-significant association between increased proximity to incinerators and the prevalence of physician-diagnosed allergic rhinitis in a Korean study. However, other studies showed no significant associations. One cross-sectional study reported a significant increase in prevalence of self-reported respiratory symptoms in individuals residing within 0–3 km from incinerators in Southern China compared to those residing within 3–8 km from the plants [48]. Miyake et al., 2005 [78] in Japan, found no association for children allergic rhinitis and school proximity to MSWIs. Shy et al., 1995 [79] assessed health effects in three U.S. communities with different types of incinerators, including MSWIs, and found no link between exposure and increased prevalence of chronic or acute respiratory symptoms. In a follow-up study Mohan et al., 2000 [59] also found no significant association between MSWIs exposure and respiratory symptoms in these communities. Additionally, Fonte et al., 2017, [52] conducted a study in Italy, using both case–control and cohort designs to evaluate hospitalizations in communities near the Busto Arsizio MSWI. The study found no significant excess risk of hospitalization for various respiratory conditions, including pneumonia, influenza, and diseases of the upper respiratory tract [52].

The narrative review of cardiovascular and respiratory outcomes revealed mixed findings regarding the association with MSWI exposure. While the majority of studies did not find consistent or systematic associations, a few high-quality studies suggested possible weak signals, pointing to a potential but uncertain increase in the risk of cardiovascular and respiratory diseases. However, these indications were limited in number and not consistently observed across the overall body of evidence.

Other outcomes

All-cause mortality and hospitalization

A total of 5 studies investigated the potential impact of residential exposure to MSWIs on all-cause mortality and hospitalization rates [49, 51, 54, 55, 75]. Three studies observed a link between MSWIs and an increase in all-cause mortality [49, 51, 53].

A study of residents near the San Zeno incinerator in Italy found a 10% increase in overall mortality risk among men exposed to the highest levels of PM10 emissions [53]. A significant increase in all-cause mortality was also observed among men exposed to the highest levels of emissions from the Pisa incinerator [51]. An Italian study on the Forlì incinerator observed no specific trend in all-cause mortality rates in relation to heavy metals concentrations, however significant excess risk of all-cause mortality was observed among exposed men and women [55]. Additionally, a non-statistically significant increase in all-cause mortality was seen among women in a cohort near the Valmadrera incinerator [49]. In contrast, a study examining villages near a MSWI in Jiangsu Province (China) found that residents in downwind villages had higher age-adjusted mortality rates compared to those in upwind villages [75]. However, standardized mortality rates (SMR) showed no significant changes before and after the incinerator's operation, suggesting that factors unrelated to the MSWI may have influenced the differences [75]. Romanelli et al., 2019 [51] found an excess of hospitalization from natural cause in men from the highest exposure class, while no significant association was found for this outcome in a cohort study focusing on the Lazio region [54].

Other health outcomes

Other health outcomes were investigated in three studies [49, 53, 57]. Among these, two studies found associations between exposure to MSWIs and psychiatric disorders and urinary diseases, respectively [49, 53]. Piccinelli et al., 2022 [49] reported a significantly increased risk of hospitalization due to psychiatric disorders in an Italian cohort of women exposed to high levels of PM10 emissions from the Valmadrera incinerator. In the same study, a reduced risk of mortality from digestive system diseases was observed among men highly exposed to modelled PM10 concentrations compared to those with lower exposure levels [49]. These findings were consistent with those of Minichilli et al., 2016 [53], who examined mortality and hospitalization in the population surrounding the San Zeno incinerator. Their study also showed a significant decrease in mortality from digestive diseases among females exposed to higher PM10 concentrations (highlighted by two asterisks in heat map in Additional file 10) [53]. However, no significant results were observed for hospitalization due to digestive system diseases in either study [49, 53]. Minichilli et al., 2016 [53] also reported an excess risk of hospitalization due to urinary diseases among men and individuals of both sexes exposed to MSWI emissions, with increases of 36% and 24%, respectively, but a reduced risk of digestive system diseases (in yellow colour the heat map). Meanwhile, a cross-sectional study by Kim et al., 2022 [57] investigating the relationship between environmental diseases and MSWI exposure in Korea did not find a significant association between residential proximity to incinerators and atopic dermatitis.

Children's health

Four studies explored the impact of exposure to or proximity to MSWIs on children's health [54, 76–78]. Two of these studies presented contrasting results regarding the effect of MSWIs on children's development [76, 77], while one study found a suggestion of increase in hospital admissions for natural cause but not for respiratory diseases in Italy [54] and another study found an association between symptoms in children and proximity to incinerators [78].

Studies on children's health and municipal solid waste incinerators (MSWIs) suggest potential risks, though findings are inconsistent. Lung et al., 2013 [77] found that living within 3 km of an incinerator increased the risk of developmental delays, particularly in gross motor skills at 6 and 36 months, with a stronger effect in breastfed children. However, a follow-up study [76] suggested that the adverse effects on social development at 6 months were temporary, with children catching up later. A cohort study using dispersion modelling found a borderline increase in all-natural cause of mortality (HR =1.12, 0.96–1.31) but no significant rise in respiratory diseases or asthma hospitalizations among children living within

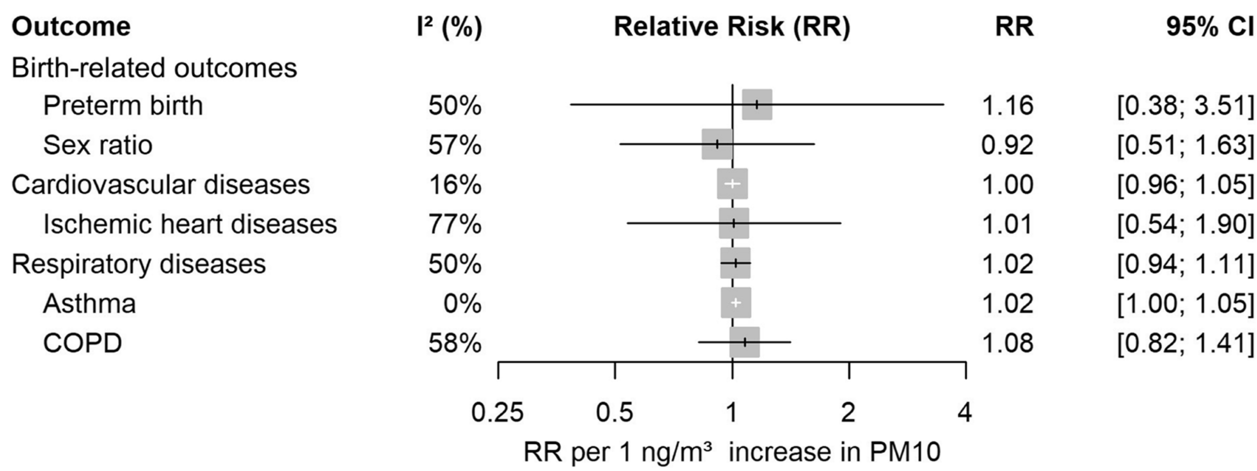

Fig. 2 Pooled risks of neonatal and hospitalization outcomes linked to PM10 exposure from MSWIs. Summary of random effects pooled risks of neonatal outcomes and hospitalization due to cardiovascular and respiratory conditions associated with a 1 ng/m^3 increase in PM10 exposure from MSWIs

7 km of two incinerators in Central Italy [54]. Miyake et al., 2005 [78] reported an increased prevalence of headaches, stomach aches, and fatigue in children living closer to MSWIs but found no association with atopic dermatitis.

Concerning other health outcomes, weak signals of increased risk of all-cause mortality, natural-cause hospitalization, urinary system diseases and psychiatric disorders emerged from few high-quality studies, as shown in heatmap in Additional file 10. However, these appeared to be localized findings, not consistent when considering the broader body of evidence. For children's health outcomes, some increased risks were observed, but these were exclusively reported in studies of low methodological quality.

Quantitative summary of evidence

Due to substantial heterogeneity among the included studies, only five high-quality cohort studies were suitable for meta-analysis [36, 38, 49, 53, 54]. All studies employed dispersion models to assess exposure to MSWI-related PM10. Accordingly, a quantitative synthesis of the evidence was performed for neonatal outcomes (preterm births and sex ratio at birth) as well as cardiovascular and respiratory outcomes, including cardiovascular diseases, ischemic heart disease, respiratory diseases, COPD and asthma. For the latter group, the meta-analysis estimated the risk of hospitalization associated with specific outcomes. For each outcome, data were pooled/derived from three studies. Outcome-specific pooled effect estimates per 1 ng/m^3 increase in PM10 are shown in Fig. 2, while the detailed forest plots with individual study results are provided in Additional file 1 (Figures A1-A7). For each outcome, a maximum of three effect estimates were available.

For neonatal outcomes, three studies [36, 38, 49] were included in the meta-analysis suggesting an increased risk for preterm birth, although the results were not statistically significant (HR 1.16; 95% CI [0.38–3.51]; I^2= 50%) while no increased risk was observed for sex ratio (HR 0.92; 95% CI [0.51–1.63]; I^2= 57%) (see Figure A1 and A2 in Additional file 1). No overall increased risk of hospitalization for cardiovascular diseases was observed in the entire cohort (HR 1.00; 95% CI [0.96–1.05]; I^2= 16%;3 studies), with similar results in men (HR 1.00; 95% CI [0.92–1.10]; I^2= 31%; 3 studies) and in women (HR 1.00; 95% CI [1.00–1.00]; I^2= 0%; 3 studies) (see Figure A3 in Additional file 1). No significant overall risk of IHD hospitalization was observed (HR 1.01; 95% CI [0.54–1.90]; I^2= 77%). Subgroup analyses by sex showed no significant differences between men (HR 0.98; 95% CI [0.50–1.91]; I^2= 76%; 3 studies) and women (HR 1.05; 95% CI [0.70–1.57]; I^2= 54%) (see Figure A4 in Additional file 1). A slight nonsignificant excess risk for hospitalization from respiratory diseases in the whole cohort was observed (HR 1.02; 95%CI [0.94–1.11]; I^2 =50%; n° of studies), and in men (HR 1.02; 95% CI [0.92–1.14]; I^2 =43%; 3 studies) (see Figure A5 in Additional file 1). There was a slight, though not statistically significant, increased risk of hospitalization for chronic obstructive pulmonary disease (COPD), in the whole cohort (HR 1.08; 95% CI [0.82–1.41]; I^2 =58%), more pronounced particularly among men (HR 1.11; 95% CI [0.74–1.66]; I^2 =64%), while no excess of risk was observed in women (see Figure A6 in Additional file 1). A slight and statistically significant increased risk of hospitalization for asthma was observed (HR 1.02; 95%

CI [1.00–1.05]; $I^2 = 0\%$). Due to the limited sample size for sex-specific categories and the low pollutant concentrations defining exposure categories, stratified analysis by sex for asthma was not feasible (see Figure A7 in Additional file 1).

Overall, a moderate level of heterogeneity was observed for most of the considered outcomes, as indicated by Higgins' I^2 values ranging from 30 to 60%, with more marked values for ischemic heart disease, particularly in men. As for publication bias, funnel plots were carried out (see Figure A8–A22 in Additional File 1). However, the interpretation of these plots, as well as the reliability of the pooled estimates, is limited by the small number of studies included in the metanalyses (n =3 for each outcome) and the aforementioned heterogeneity. In line with the recommendations of the Cochrane Handbook [80], we did not perform formal statistical tests for funnel plot asymmetry, such as Egger's test, because these methods lack sufficient power when fewer than ten studies are included in a meta-analysis and could therefore yield unreliable results.

Discussion

This review updates the long-term health effects of municipal solid waste incinerators (MSWIs) on nearby resident populations, incorporating global evidence from the past three decades. A systematic literature search without language restrictions identified 51 studies, yielding over 500 effect estimates (see heat maps in Additional file 2–10) with high heterogeneity in study design, exposure measurement, and health outcomes. Some studies provided multiple effect estimates for the same outcome (e.g., by gender or different exposure metrics), complicating the assessment of specific exposure-outcome associations. Unlike previous reviews that focused on specific diseases [12] or presented narrative summaries [15, 17], this review aimed to provide both a quantitative and comprehensive synthesis of all potential adverse health effects linked to MSWI exposure. The main findings indicate a slight increase in hospitalization risk for cardiovascular and respiratory diseases (supported by meta-analysis and narrative synthesis). Notably, cardiovascular and respiratory outcomes were among the most frequently investigated, with a larger proportion of high-quality studies compared to other outcomes. Although the observed associations were generally weak and sometimes inconsistent, these findings should be considered with caution in the interest of public health and transparency, as they reflect a signal partially recurring across the body of evidence, despite the variability in results. A potential rise in Non-Hodgkin's lymphoma risk also emerged (highlighted only by narrative synthesis and based on limited studies). While analyzing the evidence, we also considered the potential role of sex-specific differences. Although some individual studies reported sex-specific differences in health effects, these results were not consistent across the overall body of evidence, and no clear or systematic pattern emerged for any outcome.

Beyond the slight signals previously mentioned, significant uncertainty remains regarding the health impact of MSWIs on nearby populations, partly due to the heterogeneity in methods and exposure assessment. No clear excess was found for adverse pregnancy outcomes, sarcomas, or laryngeal cancer, which were suggested in previous reviews [12, 15, 17]. The specificity of the exposure may hinder the detection of small risk signals, as populations exposed to point-source pollution like incinerators are typically small, reducing statistical power. Additionally, exposure levels to MSWIs are very low, often thousands of times lower than urban PM10 exposure (e.g., median PM10 levels around MSWIs range from 0.339 ng/m^3 in England and Scotland to 0.48 ng/m^3 in Emilia-Romagna, Italy [37, 43]). The evolving nature of incineration technology also affects both pollutant type and concentration, as newer plants emit fewer pollutants. Notably, for cancer outcomes, the strongest associations were found in studies analyzing exposure periods before 2000, before technological upgrades and stricter environmental regulations [9, 11, 50, 63, 67, 69, 70, 74]. However, the lack of detailed information on incinerator technology in the included studies often prevented distinguishing between older and modern MSWIs. Moreover, isolating the health effects of specific pollutants, such as particulate matter, remains difficult due to the presence of other local emission sources. These factors, along with variability in study designs and exposure assessments, contribute to the heterogeneity of results, complicating overall interpretation, as also noted by other authors [15].

The potential long-term effects of MSWIs on cardiovascular and respiratory outcomes are biologically plausible. Inhalation of air pollutants such as PM and NO_x is a well-established risk factor for chronic respiratory diseases, including asthma and COPD [81, 82]. Once deposited in the alveolar space, these pollutants disrupt pro-inflammatory signaling pathways, triggering oxidative stress and inflammation. This leads to excessive production of reactive oxygen species (ROS), causing cellular damage due to an imbalance between ROS and antioxidants. Chronic inflammation can further harm surrounding tissues through the release of inflammatory mediators and recruitment of immune cells [83, 84]. Moreover, ultrafine particles and inflammatory compounds can enter systemic circulation, exerting detrimental effects on the cardiovascular system. Pulmonary pollutants may also interfere with neuroendocrine pathways, affecting autonomic regulation of cardiac function

[83]. In line with this biological plausibility, this systematic review identified weak but consistent signals of association between MSWI exposure and cardiovascular and respiratory diseases, including ischemic heart disease (IHD), COPD, and asthma. These associations emerged from high-quality evidence, though based on a limited number of studies from both narrative and quantitative synthesis.

A meta-analysis for cancer-related outcomes was not feasible due to high study heterogeneity. This potentially reflects underlying differences in population characteristics, exposure assessment methods, outcome definitions, and adjustment for confounders across studies. However, it should be noted that even the I^2 statistic can be biased due to the low number of studies included in meta-analysis [85]. Exposure to MSWIs appears associated with an increased risk of Non-Hodgkin's lymphoma (NHL), though findings are inconsistent. Only seven of 14 studies reported a significant association, primarily from low-quality evidence. Three positive studies were conducted in the same French department [11, 64, 74], one covered four French departments [69], and the remaining significant results came from two ecological studies [71, 72] and a case–control study linking NHL to PCDD/F exposure but not PM2.5 [50]. Conversely, four high-quality cohort studies found no significant association [49, 51, 53, 54]. The concentration of positive findings in lower-quality studies and a specific geographic area raises concerns about bias and limits generalizability. NHL, a heterogeneous disease with uncertain etiology, has been linked to chronic exposure to chemicals such as 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) [86]. TCDD may promote carcinogenesis through genetic mutations, epigenetic alterations in oncogenes and tumor suppressor genes, disruption of cytokine and hormone signaling, oxidative damage, and immune suppression [87]. No clear effect of MSWIs was observed for soft tissue sarcomas or lung cancer, despite their known link to dioxins and particulate matter [86]. A possible explanation is the low pollutant emissions from modern MSWIs, which may be insufficient to significantly increase risk. PM10 levels from MSWIs ranged from 0.155 to 0.91 ng/m^3 across studies [36–38, 43], contributing minimally to overall pollution.

This review identified isolated associations from high-quality studies [49, 51, 55] for pleural, stomach, colorectal, and breast cancers, as well as lympho-hematopoietic cancers and leukemia. However, no clear effect of MSWIs on pregnancy outcomes was found, consistent with mixed results from previous reviews [15, 17]. Given the susceptibility of pregnant women to environmental exposures, even small effects could have significant public health implications. Biologically, MSWI-related air pollution may impact pregnancy through inflammation and oxidative stress, impairing placental vascularization and altering signaling pathways, leading to adverse birth outcomes such as preterm birth and fetal growth abnormalities. Additionally, pollutants like PM and NO2 may induce epigenetic modifications and endocrine imbalances, affecting fetal development and increasing the risk of poor birth outcomes [8].

Psychological stress is another potential health impact for populations living near incinerators, as observed in other contaminated sites [88–90]. A major source of stress is uncertainty about possible health effects [88, 89]. In this review, only one study assessed mental health impacts, finding effects exclusively in women [49]. Previous research has linked environmental worry to adverse health outcomes in studies on incinerators [57], landfills [91], and other contaminated sites [92], though most evidence comes from qualitative research not covered in this review. Greater attention should be given to public risk perception in epidemiological studies, as neglecting these concerns can erode trust in authorities and lead to public resistance against research findings [93].

Beyond health concerns, incinerators pose environmental issues, particularly regarding their carbon footprint. Although sometimes promoted as a low-carbon energy source, waste-to-energy plants have a significant environmental impact. The carbon intensity of energy from waste incineration is twice the EU electricity grid average and exceeds that of fossil fuels like natural gas, contributing to climate change [94]. These environmental concerns may further heighten public anxiety and opposition to incineration facilities. A consequential environmental epidemiology approach, incorporating input from stakeholders such as community organizations, policymakers, and industry while involving affected communities, is the most effective strategy for addressing concerns in contaminated areas [95].

The evidence from this systematic review is largely based on studies with a high or very high risk of bias, accounting for approximately 70% of the 51 included studies. The main limitations stem from poor exposure assessment and inadequate control of confounding factors. Many studies suffered from exposure misclassification, often relying on plant proximity as a proxy for exposure rather than using dispersion models that integrate MSWI emissions, plant characteristics, meteorology, and geographic data to generate more precise spatial estimates [96]. Moreover, actual exposure levels may differ from estimated ones due to population mobility and additional intake sources, such as food consumption and dermal contact [96]. Another critical issue was the insufficient adjustment for potential confounders, including socioeconomic status, smoking habits, and other environmental or occupational exposures, particularly in case–control and cross-sectional studies. To systematically address these sources of bias, we applied the Navigation Guide tool, which was specifically developed for the evaluation of observational studies in the field of environmental health [27]. Our primary aim was to provide a validated, domain-specific assessment tool as previously recommended [80, 97], in order to better identify and interpret critical domains of bias across the body of evidence. Additionally, we customized the Navigation Guide using the OHAT Risk of Bias Tool [98] for key domains of exposure assessment and confounding, which are particularly relevant for studies investigating health effects of environmental exposures like MSWI emissions. Until a standardized risk of bias tool is established, using validated, topic-focused tools and providing transparent criteria and rationale behind judgement, offers a suitable and replicable framework for assessing the quality of the entire body of evidence.

Although no restrictions were applied regarding language or publication date, only 51 studies were ultimately included in this review. Approximately one-third of potentially eligible studies were excluded during full-text screening due to the absence of quantitative associations or their status as unpublished material (e.g., conference posters or abstracts). The included studies originated from a limited number of countries (Italy, France, UK, US, China, Taiwan, Japan, and Korea), raising questions about the absence of studies from other regions, particularly in Europe, where MSWIs are a key component of waste management. The inclusion of grey literature—often underrepresented due to publication bias—could have increased the number of studies considered but might have also compromised overall study quality.

Conclusions

This review provides an updated synthesis of the long-term health effects of MSWI exposure on nearby populations. The findings suggest a slight signal of increased risk for cardiovascular and respiratory hospitalizations, supported by both narrative and quantitative synthesis, and a possible association with non-Hodgkin's lymphoma, although this was identified only in narrative synthesis and based on limited and low quality evidence. No clear associations were observed for pregnancy outcomes, soft tissue sarcomas, or other cancer types.

Overall, uncertainty remains regarding the health effects of municipal solid waste incinerators, largely due to methodological limitations, substantial heterogeneity in study designs, and weak evidence. These uncertainties are compounded by the relatively low pollutant concentrations emitted by MSWIs and the small size of the exposed population, making risk detection and result comparability challenging. Additionally, the observed associations could stem from unmeasured confounders or psychological stress linked to living in an industrially contaminated area [88].

To improve future research, it is essential to standardize methodologies, enhance study quality, and adopt robust, consistent analytical approaches. These steps are critical for informing public health decisions and ensuring transparent risk communication, particularly for communities near incinerators who frequently express concerns about potential health risks. Providing clear, evidence-based guidance will help foster public trust, reduce uncertainty, and support policies that effectively safeguard public health.

Abbreviations

MSW	Municipal Solid Waste
MSWI	Municipal Solid Waste Incinerator
WTE	Waste to Energy plants
NOx	Nitrogen Oxides
PM	Particulate Matter
PRISMA	Preferred Reporting Items for Systematic Review and Meta-Analyses
MeSH	Medical Subject Headings
PECO	Population, Exposure, Comparator, Outcome
PM10	Particulate Matter with diameter ≤ 10 µm
RoB	Risk of Bias
PM2.5	Particulate Matter with diameter ≤ 2.5 µm
PCDD/F	Polychlorinated dibenzo-p-dioxins and dibenzofurans
SO2	Sulfur dioxide
H	High risk of bias
PH	Probably High risk of bias
L	Low risk of bias
PL	Probably Low risk of bias
CA	Congenital Anomalies
CI	Confidence Interval
SGA	Small for Gestational Age
NHL	Non-Hodgkin's lymphoma
PCB	Polychlorinated biphenyl
IHD	Ischemic Heart Disease
AMI	Acute Myocardial Infarction
COPD	Chronic Obstructive Pulmonary Diseas
TBCS	Taiwan Birth Cohort Study
ROS	Reactive Oxygen Species
TCDD	Tetrachlorodibenzo-paradioxin

Supplementary Information

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Additional file 1. Details of search strategy, risk of bias assessment, exclude studies, included studies, meta-analysis results.

Additional file 2. Heatmap of associations between exposure to MSWIs and pregnancy outcomes. Results are stratified by study quality. Red colour: statistically significant increased risk in exposed population.

Additional file 3. Heatmap of associations between exposure to MSWIs and congenital anomalies (Part A). Results are stratified by study quality. Red colour: statistically significant increased risk in exposed population.

Additional file 4. Heatmap of associations between exposure to MSWIs and congenital anomalies (Part B). Results are stratified by study quality. Red colour: statistically significant increased risk in exposed population.

Additional file 5. Heatmap of associations between exposure to MSWIs and cancer outcomes in men. Results are stratified by study quality. Red colour: statistically significant increased risk in exposed population.

Additional file 6. Heatmap of associations between exposure to MSWIs and cancer outcomes in women. Results are stratified by study quality. Red colour: statistically significant increased risk in exposed population.

Additional file 7. Heatmap of associations between exposure to MSWIs and cancer outcomes in overall population. Results are stratified by study quality. Red colour: statistically significant increased risk in exposed population.

Additional file 8. Heatmap of associations between exposure to MSWIs and cardiovascular outcomes. Results are stratified by study quality. Red colour: statistically significant increased risk in exposed population.

Additional file 9. Heatmap of associations between exposure to MSWIs and respiratory outcomes. Results are stratified by study quality. Red colour: statistically significant increased risk in exposed population.

Additional file 10. Heatmap of associations between exposure to MSWIs and children's health and other adults' health outcomes. Results are stratified by study quality. Red colour: statistically significant increased risk in exposed population.

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Authors' contributions
I.B. searched the databases using the keywords and saved the identified articles. A panel discussion involving two additional researchers (M.D.S. and S.V.) clarified and eliminated discrepancies. Next, I.B. screened the titles and abstracts of the selected papers to remove those that did not meet the selection criteria. At the same time, M.D.S, S.V., and C.A. clarified and eliminated any discrepancies. I.B. read the papers and excluded irrelevant articles. The discrepancies were clarified and eliminated by discussion between the team. L.B. and A.T. took care of the statistical analysis. I.B, M.D.S., S.V., and C.A. wrote the paper. P.M. reviewed the text and contributed to the discussion of the results.

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Data availability
All data generated or analysed during this study are included in this published article [and its supplementary information files].

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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