Air pollution exposure and human health in port cities: a systematic review

Supplementary File S1. Details of search strategy, risk-of-bias assessment, study characteristics and pollutant concentrations.

Table S1. Search Strategy for MEDLINE and EMBASE (via OVID).

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Table S1. Search Strategy for MEDLINE and EMBASE (via OVID)

1. (port or ports or portuary).ti,ab.
2. maritime.ti,ab.
3. (harbour or harbor).ti,ab.
4. (pollut* or emission* or contamin* or "air quality").ti,ab.
5. (contamin* adj2 (site* or place* or plan*)).ti,ab.
6. (coastal adj2 cities).ti,ab.
7. 1 or 2 or 3 or 5 or 6
8. 4 and 7
9. (residen* or residing or city or cities or community or communities or municipality or population* or neighbourhood* or neighborhood* or neighb$uring or neighboring or urban or around or proximit* or surround* or vicinity or nearby or near or site*).ti,ab
10. animals/ not humans/
11. 8 and 9
12. (death* or mortality or morbidity or patholog* or disease* or outcome* or syndrome* or cancer* or neoplasm* or tum$r* or leukaemia or lymphoma or neoplasm* or malignant or myeloma or sarcoma or carcinoma or malignant or digestive or metabolic or endocrine or liver or pancreatic or renal or cardiovascular* or cerebrovascular or heart or respiratory or haematologic* or lymphatic or mental neurologic* or cognit* or urinary or infection* or Diabetes or Parkinson or Alzheimer or thyroid or hormonal or immunological ortransplant* or reproductive or miscarriage* or neonatal or congenital or fertility or pregnan* or birth* or preterm* or prematur*).tw,kw.
13. ((congenital adj2 malformation*) or (congenital adj2 anomal*) or (congenital adj2 defect*) or (birth adj2 defect*) or (malformative adj2 syndrome*)).ti,ab.
14. (health adj1 (effect* or consequences)).ti,ab,kw.
15. (adverse adj2 (effect* or consequence*)).tw,kw.
16. exp Hospitalization/ or exp morbidity/ or exp mortality/
17. (hospital* or mortalit* or disease* or death* or morbidity).tw,kw.
18. exp Incidence/
19. incidence.tw,kw.
20. 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19
21. 8 and 9 and 20
22. 21 not 10

Table S2. Search Strategy for Web of Science

(((((TI=((pollut* OR emission* OR contamin* OR (air NEAR/2 quality)))) OR (AB=((pollut* OR emission* OR contamin* OR (air NEAR/2 quality)))))
AND
((TI=(port OR ports OR portuary OR (maritime) OR ((harbour OR harbor)) OR ((contamin* AND (site* OR place* OR plan*))) OR ((coastal NEAR/2 cities)))) OR (AB=(port OR ports OR portuary OR (maritime) OR ((harbour OR harbor)) OR ((contamin* AND (site* OR place* OR plan*))) OR ((coastal NEAR/2 cities))))))
AND
((TI=((residen* OR residing OR city OR cities OR community OR communities OR municipality OR population* OR neighbourhood* OR neighborhood* OR neighbo$ring OR neighboring OR urban OR around OR proximit* OR surround* OR vicinity OR nearby OR "near" OR site*) NOT animal*)) OR (AB=((residen* OR residing OR city OR cities OR community OR communities OR municipality OR population* OR neighbourhood* OR neighborhood* OR neighbo$ring OR neighboring OR urban OR around OR proximit* OR surround* OR vicinity OR nearby OR "near" OR site*) NOT animal*)))
AND
((TI=(((death* OR mortality OR morbidity OR patholog* OR disease* OR outcome* OR syndrome* OR cancer* OR neoplasm* OR tumo$r* OR leukaemia OR lymphoma OR neoplasm* OR malignant OR myeloma OR sarcoma OR carcinoma OR malignant OR digestive OR metabolic OR endocrine OR liver OR pancreatic OR renal OR cardiovascular* OR cerebrovascular OR heart OR respiratory OR haematologic* OR lymphatic OR mental neurologic* OR cognit* OR urinary OR infection* OR Diabetes OR Parkinson OR Alzheimer OR thyroid OR hormonal OR immunological OR transplant* OR reproductive OR miscarriage* OR neonatal OR congenital OR fertility OR pregnan* OR birth* OR preterm* OR prematur*)) OR (((congenital NEAR/2 malformation*) OR (congenital NEAR/2 anomal*) OR (congenital NEAR/2 defect*) OR (birth NEAR/2 defect*) OR (malformation NEAR/2 syndrome*))) OR ((health NEAR/2 (effect* OR consequences))) OR ((adverse NEAR/2 (effect* OR consequence*))) OR (Hospitalization OR morbidity OR mortality) OR ((hospital* OR mortalit* OR disease* OR death* OR morbidity)) OR (Incidence) OR (incidence))) OR (AB=(((death* OR mortality OR morbidity OR patholog* OR disease* OR outcome* OR syndrome* OR cancer* OR neoplasm* OR tumo$r* OR leukaemia OR lymphoma OR neoplasm* OR malignant OR myeloma OR sarcoma OR carcinoma OR malignant OR digestive OR metabolic OR endocrine OR liver OR pancreatic OR renal OR cardiovascular* OR cerebrovascular OR heart OR respiratory OR haematologic* OR lymphatic OR mental-neurologic* OR cognit* OR urinary OR infection* OR Diabetes OR Parkinson OR Alzheimer OR thyroid OR hormonal OR immunological OR transplant* OR reproductive OR miscarriage* OR neonatal OR congenital OR fertility OR pregnan* OR birth* OR preterm* OR prematur*)) OR (((congenital NEAR/2 malformation*) OR (congenital NEAR/2 anomal*) OR (congenital NEAR/2 defect*) OR (birth NEAR/2 defect*) OR (malformation NEAR/2 syndrome*))) OR ((health NEAR/2 (effect* OR consequences))) OR ((adverse NEAR/2 (effect* OR consequence*))) OR (Hospitalization OR morbidity OR mortality) OR ((hospital* OR mortalit* OR disease* OR death* OR morbidity)) OR (Incidence) OR (incidence))) OR (AK=(((death* OR mortality OR morbidity OR patholog* OR disease* OR outcome* OR syndrome* OR cancer* OR neoplasm* OR tumo$r* OR leukaemia OR lymphoma OR neoplasm* OR malignant OR myeloma OR sarcoma OR carcinoma OR malignant OR digestive OR metabolic OR endocrine OR liver OR pancreatic OR renal OR cardiovascular* OR cerebrovascular OR heart OR respiratory OR haematologic* OR lymphatic OR mental-neurologic* OR cognit* OR urinary OR infection* OR Diabetes OR Parkinson OR Alzheimer OR thyroid OR hormonal OR immunological OR transplant* OR reproductive OR miscarriage* OR neonatal OR congenital OR fertility OR pregnan* OR birth* OR preterm* OR prematur*)) OR (((congenital NEAR/2 malformation*) OR (congenital NEAR/2 anomal*) OR (congenital NEAR/2 defect*) OR (birth NEAR/2 defect*) OR (malformation NEAR/2 syndrome*))) OR ((health NEAR/2 (effect* OR consequences))) OR ((adverse NEAR/2 (effect* OR consequence*))) OR (Hospitalization OR morbidity OR mortality) OR ((hospital* OR mortalit* OR disease* OR death* OR morbidity)) OR (Incidence) OR (incidence)))))
AND
ALL=(human* NOT animal*))

Table S3. Excluded studies and reasons for exclusion

Reference	Reason for exclusion
Akhbarizadeh R, Dobaradaran S, Amouei Torkmahalleh M, Saeedi R, Aibaghi R, Faraji Ghasemi F. Suspended fine particulate matter (PM2.5), microplastics (MPs), and polycyclic aromatic hydrocarbons (PAHs) in air: Their possible relationships and health implications. Environmental Research. 2021;192:110339. doi:10.1016/j.envres.2020.110339	No effect size calculation
Barhoumi B, Castro-Jiménez J, Guigue C, et al. Levels and risk assessment of hydrocarbons and organochlorines in aerosols from a North African coastal city (Bizerte, Tunisia). Environmental Pollution. 2018;240:422-431. doi:10.1016/j.envpol.2018.04.109	No effect size calculation
Bauleo L, Ruggieri F, Bucci S, et al. La valutazione dell'esposizione a contaminanti ambientali: modelli di dispersione e biomonitoraggio umano. Epidemiol Prev. 2019;43(4):260-269. doi:10.19191/EP19.4.P260.076.	No effect size calculation
Benedetti M, De Santis M, Manno V, et al. Spatial distribution of kidney disease in the contaminated site of Taranto (Italy). American J Industrial Med. 2017;60(12):1088-1099. doi:10.1002/ajim.22781	No effect size calculation
Billet S, Al Zallouha M, Landkocz Y, et al. Urban air pollution fine particulate matter exposure: Biomarkers of carcinogenesis modulated by people ageing. Toxicology Letters. 2015;238(2):S63. doi:10.1016/j.toxlet.2015.08.225	No effect size calculation
Binazzi A, Zona A, Marinaccio A, et al. [SENTIERI-ReNaM: Results]. Epidemiol Prev. 2016;40(5Suppl1):19-98.	Wrong exposure
Broome RA, Cope ME, Goldsworthy B, et al. The mortality effect of ship-related fine particulate matter in the Sydney greater metropolitan region of NSW, Australia. Environment International. 2016;87:85-93. doi:10.1016/j.envint.2015.11.012	No effect size calculation
Callan AC, Winters M, Barton C, Boyce M, Hinwood AL. Children's Exposure to Metals: A Community-Initiated Study. Arch Environ Contam Toxicol. 2012;62(4):714-722. doi:10.1007/s00244-011-9727-2	Wrong exposure
Chen C, Saikawa E, Comer B, Mao X, Rutherford D. Ship Emission Impacts on Air Quality and Human Health in the Pearl River Delta (PRD) Region, China, in 2015, With Projections to 2030. GeoHealth. 2019;3(9):284-306. doi:10.1029/2019GH000183	No effect size calculation
Chen L, Liu W, Tao S, Liu W. Spatiotemporal variations and source identification of atmospheric nitrated and oxygenated polycyclic aromatic hydrocarbons in the coastal cities of the Bohai and Yellow Seas in northern China. Chemosphere. 2021;279:130565. doi:10.1016/j.chemosphere.2021.130565	No effect size calculation

Chen Y, Lv D, Li X, Zhu T. PM2.5-bound phthalates in indoor and outdoor air in Beijing: Seasonal distributions and human exposure via inhalation. Environmental Pollution. 2018;241:369-377. doi:10.1016/j.envpol.2018.05.081	No effect size calculation
Comba P, Bianchi F, Conti S, et al. [SENTIERI Project: rationale and objectives]. Epidemiol Prev. 2011;35(5-6 Suppl 4):17-19.	Results replicated elsewhere
Comba P, Iavarone I, Bianchi F, et al. Multicentre Mortality Study of Contaminated Sites of National Concern in Italy: Epidemiology. 2011;22:S58-S59. doi:10.1097/01.ede.0000391841.13375.a6	No effect size calculation
Comba P, Pirastu R, Conti S, et al. [Environment and health in Taranto, southern Italy: epidemiological studies and public health recommendations]. Epidemiol Prev. 2012;36(6):305-320.	Wrong exposure
Comba P, Ricci P, Iavarone I, et al. Cancer incidence in Italian contaminated sites. Ann Ist Super Sanita. 2014;50(2):186-191. doi:10.4415/ANN_14_02_13	Wrong exposure
Comba P, Zona A, Pirastu R, et al. [SENTIERI-ReNaM: Rationale and objectives]. Epidemiol Prev. 2016;40(5Suppl1):13-15.	Results replicated elsewhere
Crocetti E, Pirastu R, Buzzoni C, et al. [SENTIERI Project: results]. Epidemiol Prev. 2014;38(2 Suppl 1):29-124.	Wrong exposure
Czechowski PO, Piksa K, Da Browiecki P, et al. Financing Costs and Health Effects of Air Pollution in the Tri-City Agglomeration. Front Public Health. 2022;10:831312. doi:10.3389/fpubh.2022.831312	No effect size calculation
Dhondt S, Le Xuan Q, Vu Van H, Hens L. Environmental health impacts of mobility and transport in Hai Phong, Vietnam. Stoch Environ Res Risk Assess. 2011;25(3):363-376. doi:10.1007/s00477-010-0374-3	No effect size calculation
dos Santos-Silva JC, Potgieter-Vermaak S, Medeiros SHW, et al. A new strategy for risk assessment of PM2.5-bound elements by considering the influence of wind regimes. Sci Total Environ. 2023;872:162131. doi:10.1016/j.scitotenv.2023.162131.	No port area
Euzebio CS, Ornellas Meire R, Da Silveira Rangel G, et al. Passive air sampler-derived concentrations and carcinogenic potential of PAHs in oil/gas production city (Macaé, Brazil). Rev Bras Ciênc Ambient. 2022;57(4):594-605. doi:10.5327/Z2176-94781431	No effect size calculation
Fano V, Forastiere F, Papini P, Tancioni V, Di Napoli A, Perucci CA. [Mortality and hospital admissions in the industrial area of Civitavecchia, 1997-2004]. Epidemiol Prev. 2006;30(4-5):221-226.	No effect size calculation

Fazzo L, Minichilli F, Manno V, et al. [Global evaluation of the mortality and hospitalization in the Italian contaminated sites included in the SENTIERI project]. Epidemiol Prev. 2023;47(1-2 Suppl 1):366-374. doi:10.19191/EP23.1-2-S1.009	Wrong exposure
Giannico OV, Carone S, Tanzarella M, et al. Environmental pressures, tumor characteristics, and death rate in a female breast cancer cohort: a seven-years Bayesian survival analysis using cancer registry data from a contaminated area in Italy. Front Public Health. 2023;11:1310823. doi:10.3389/fpubh.2023.1310823	Wrong population
Gilliland F, Avol E, McConnell R, et al. The Effects of Policy-Driven Air Quality Improvements on Children's Respiratory Health. Res Rep Health Eff Inst. 2017;2017(190):1-75.	No port area
Graham AM, Pringle KJ, Arnold SR, et al. Impact of weather types on UK ambient particulate matter concentrations. Atmospheric Environment: X. 2020;5:100061. doi:10.1016/j.aeaoa.2019.100061	No effect size calculation
Huang H, Woodruff TJ, Baer RJ, et al. Investigation of association between environmental and socioeconomic factors and preterm birth in California. Environ Int. 2018;121(Pt 2):1066-1078. doi:10.1016/j.envint.2018.07.027	No port area
Iakovides M, Stephanou EG, Apostolaki M, et al. Study of the occurrence of airborne Polycyclic Aromatic Hydrocarbons associated with respirable particles in two coastal cities at Eastern Mediterranean: Levels, source apportionment, and potential risk for human health. Atmospheric Environment. 2019;213:170-184. doi:10.1016/j.atmosenv.2019.05.059	No effect size calculation
Iavarone I, Buzzoni C, Stoppa G, Steliarova-Foucher E, SENTIERI-AIRTUM Working Group. Cancer incidence in children and young adults living in industrially contaminated sites: from the Italian experience to the development of an international surveillance system. Epidemiol Prev. 2018;42(5-6S1):76-85. doi:10.19191/EP18.5-6.S1.P076.090	Wrong exposure
Kethireddy SR, Adegoye GA, Tchounwou PB, et al. The status of geo-environmental health in Mississippi: Application of spatiotemporal statistics to improve health and air quality. AIMS Environ Sci. 2018;5(4):273-293. doi:10.3934/environsci.2018.4.273	No port area
Lara R, Suárez-Peña B, Megido L, et al. Health risk assessment of potentially toxic elements in the dry deposition fraction of settleable particulate matter in urban and suburban locations in the city of Gijón, Spain. Journal of Environmental Chemical Engineering. 2021;9(6):106794. doi:10.1016/j.jece.2021.106794	No effect size calculation
Mangia C, Bruni A, Cervino M, Gianicolo EAL. Sixteen-year air quality data analysis of a high environmental risk area in Southern Italy. Environ Monit Assess. 2011;183(1-4):555-570. doi:10.1007/s10661-011-1940-y	No effect size calculation

Marinaccio A, Binazzi A, Comba P, et al. [SENTIERI-ReNaM: Materials and methods]. Epidemiol Prev. 2016;40(5Suppl1):16-18.	Results replicated elsewhere
Marshall EG, Harris G, Wartenberg D. Oral cleft defects and maternal exposure to ambient air pollutants in New Jersey. Birth Defects Res A Clin Mol Teratol. 2010;88(4):205-215. doi:10.1002/bdra.20650	No port area
Martellini T, Giannoni M, Lepri L, Katsoyiannis A, Cincinelli A. One year intensive PM2.5 bound polycyclic aromatic hydrocarbons monitoring in the area of Tuscany, Italy. Concentrations, source understanding and implications. Environ Pollut. 2012;164:252-258. doi:10.1016/j.envpol.2011.12.040	No port area
Martuzzi M, Mitis F, Pirastu R, et al. [Global burden of mortality in Italian polluted sites]. Epidemiol Prev. 2011;35(5-6 Suppl 4):153-162.	No effect size calculation
Mason TG, Chan KP, Schooling CM, et al. Air quality changes after Hong Kong shipping emission policy: An accountability study. Chemosphere. 2019;226:616-624. doi:10.1016/j.chemosphere.2019.03.173	No effect size calculation
Megido L, Suárez-Peña B, Negral L, Castrillón L, Fernández-Nava Y. Suburban air quality: Human health hazard assessment of potentially toxic elements in PM10. Chemosphere. 2017;177:284-291. doi:10.1016/j.chemosphere.2017.03.009	No effect size calculation
Mei F, Renzi M, Bonifazi M, et al. Long-term effects of air pollutants on respiratory and cardiovascular mortality in a port city along the Adriatic sea. BMC Pulm Med. 2023;23(1):395. doi:10.1186/s12890-023-02629-8	No effect size calculation
Meng YY, Su JG, Chen X, Molitor J, Yue D, Jerrett M. Improvements in Air Quality and Health Outcomes Among California Medicaid Enrollees Due to Goods Movement Actions. Res Rep Health Eff Inst. 2021;2021(205):1-61.	No effect size calculation
Mincuzzi A, Carone S, Galluzzo C, et al. Gender differences, environmental pressures, tumor characteristics, and death rate in a lung cancer cohort: a seven-years Bayesian survival analysis using cancer registry data from a contaminated area in Italy. Front Public Health. 2024;11:1278416. doi:10.3389/fpubh.2023.1278416	Wrong exposure
Mutlu A, Lee BK, Park GH, Yu BG, Lee CH. Long-term concentrations of airborne cadmium in metropolitan cities in Korea and potential health risks. Atmospheric Environment. 2012;47:164-173. doi:10.1016/j.atmosenv.2011.11.019	Wrong exposure
Mutlu A, Lee BK. Airborne lead levels in the Korean peninsula: characterization of temporal and spatial patterns and cancer risk analysis. Environ Sci Pollut Res. 2012;19(6):2125-2137. doi:10.1007/s11356-011-0712-0	No effect size calculation

Nirmalkar J, Lee K, Ahn J, Lee J, Song M. Comparisons of Spatial and Temporal Variations in PM2.5-Bound Trace Elements in Urban and Rural Areas of South Korea, and Associated Potential Health Risks. Atmosphere. 2023;14(4):753. doi:10.3390/atmos14040753	No port area
Ohura T, Amagai T, Fusaya M. Regional assessment of ambient volatile organic compounds in an industrial harbor area, Shizuoka, Japan. Atmospheric Environment. 2006;40(2):238-248. doi:10.1016/j.atmosenv.2005.09.064	No outcome
Parvathi M, Sandhya S, Gorikapudi DR. The Role of Environmental Pollutants in the Incidence of Contact Dermatitis: A Prospective Cohort Study.	Wrong exposure
Perez L, Künzli N, Avol E, et al. Global Goods Movement and the Local Burden of Childhood Asthma in Southern California. Am J Public Health. 2009;99(S3):S622-S628. doi:10.2105/AJPH.2008.154955	No effect size calculation
Perrino C, Gilardoni S, Landi T, et al. Air Quality Characterization at Three Industrial Areas in Southern Italy. Front Environ Sci. 2020;7:196. doi:10.3389/fenvs.2019.00196	No outcome
Pilotto LS, Smith BJ, Nitschke M, Ruffin RE, Mitchell R. Industry, air quality, cigarette smoke and rates of respiratory illness in Port Adelaide. Australian and New Zealand Journal of Public Health. 1999;23(6):657-660. doi:10.1111/j.1467-842X.1999.tb01556.x	No effect size calculation
Pirastu R, Ancona C, Iavarone I, Mitis F, Zona A, Comba P. SENTIERI Project. Mortality study of residents in Italian polluted sites: evaluation of the epidemiological evidence. Epidemiol Prev. 2010 Sep-Dec;34(5-6 Suppl 3):1-96. Italian.	Results replicated elsewhere
Pirastu R, Comba P, Iavarone I, et al. Environment and Health in Contaminated Sites: The Case of Taranto, Italy. Journal of Environmental and Public Health. 2013;2013:1-20. doi:10.1155/2013/753719	Wrong exposure
Pirastu R, Pasetto R, Zona A, et al. The Health Profile of Populations Living in Contaminated Sites: Sentieri Approach. Journal of Environmental and Public Health. 2013;2013:1-13. doi:10.1155/2013/939267	No port area
Pirastu R, Ricci P, Comba P, et al. [SENTIERI Project: discussion and conclusions]. Epidemiol Prev. 2014;38(2 Suppl 1):125-133.	Wrong exposure
Proias G, Nastos PT, Moustris KP, Paliatsos AthanasiosG. Weekend—Weekday Effect Assessment of PM10 in Volos, Greece (2010-2014). In: Karacostas T, Bais A, Nastos PT, eds. Perspectives on Atmospheric Sciences. Springer Atmospheric Sciences. Springer International Publishing; 2017:957-962. doi:10.1007/978-3-319-35095-0_136	No outcome
Ramacher MOP, Tang L, Moldanová J, Matthias V, Karl M, Fridell E, Johansson L. The impact of ship emissions on air quality and human health in	No effect size calculation

the Gothenburg area - Part II: Scenarios for 2040. Atmos Chem Phys. 2020;20:10667-10686. doi:10.5194/acp-20-10667-2020.	
Robert JJ, Chiemeka IU, Chineke TC. Health impact assessments of particulate matter pollution from construction sites in Port Harcourt and Owerri Metropolises, Nigeria. Air Qual Atmos Health. 2023;16(5):873-879. doi:10.1007/s11869-023-01309-0.	No effect size calculation
Sarmiento H, Potgieter-Vermaak S, Borillo GC, et al. BTEX profile and health risk at the largest bulk port in Latin America, Paranaguá Port. Environ Sci Pollut Res Int. 2023;30(22):63084-63095. doi:10.1007/s11356-023-26508-1.	No effect size calculation
Schlink U, Steinert C, Richter M, et al. Environmental Health in Port and Harbor Areas. In: Linkov I, Wenning RJ, Kiker GA, eds. Managing Critical Infrastructure Risks. Springer; 2007:411-422. doi:10.1007/978-1-4020-6385-5_23.	No effect size calculation
Tang L, Ramacher MOP, Moldanová J, et al. The impact of ship emissions on air quality and human health in the Gothenburg area - Part 1: 2012 emissions. Atmos Chem Phys. 2020;20(12):7509-7530. doi:10.5194/acp-20-7509-2020	No effect size calculation
Tripathi S, Chakraborty A, Mandal D. Spatial variations in physico-chemical characteristics of PM2.5 in an urban coastal city of India and associated health risks. J Atmos Chem. 2023;80(3):211-226. doi:10.1007/s10874-023-09448-5	No port area
Tsai JH, Gu WT, Chung II, Chiang HL. Airborne Air Toxics Characteristics and Inhalation Health Risk Assessment of a Metropolitan Industrial Complex. Aerosol Air Qual Res. 2019;19(11):2477-2489. doi:10.4209/aaqr.2019.08.0422	No effect size calculation
Tsai MY, Hoek G, Eeftens M, et al. Spatial variation of PM elemental composition between and within 20 European study areas--Results of the ESCAPE project. Environ Int. 2015;84:181-192. doi:10.1016/j.envint.2015.04.015	No outcome
Vecchi S, Benedetti M, Fazzo L, Bruno C, Zona A. Progetto SENTIERI: revisione della letteratura scientifica sull'associazione tra fonti di esposizione ambientale in siti contaminati ed esiti di salute. Epidemiol Prev. 2023;47(1-2 Suppl 1):289-309. doi:10.19191/EP23.1-2-S1.004.	Systematic review
Viana M, Rizza V, Tobías A, et al. Estimated health impacts from maritime transport in the Mediterranean region and benefits from the use of cleaner fuels. Environment International. 2020;138:105670. doi:10.1016/j.envint.2020.105670	No effect size calculation
Vu HNK, Ha QP, Nguyen DH, et al. Poor Air Quality and Its Association with Mortality in Ho Chi Minh City: Case Study. Atmosphere. 2020;11(7):750. doi:10.3390/atmos11070750	No effect size calculation

Wang Y, Zhang H, Zhang X, et al. PM-Bound Polycyclic Aromatic Hydrocarbons and Nitro-Polycyclic Aromatic Hydrocarbons in the Ambient Air of Vladivostok: Seasonal Variation, Sources, Health Risk Assessment and Long-Term Variability. IJERPH. 2022;19(5):2878. doi:10.3390/ijerph19052878	Wrong exposure
Wu SP, Cai MJ, Xu C, et al. Chemical nature of PM2.5 and PM10 in the coastal urban Xiamen, China: Insights into the impacts of shipping emissions and health risk. Atmospheric Environment. 2020;227:117383. doi:10.1016/j.atmosenv.2020.117383	No effect size calculation
Xiong Y, Bari MdA, Xing Z, Du K. Ambient volatile organic compounds (VOCs) in two coastal cities in western Canada: Spatiotemporal variation, source apportionment, and health risk assessment. Science of The Total Environment. 2020;706:135970. doi:10.1016/j.scitotenv.2019.135970	No effect size calculation
Xu J, Jia C, Yu H, et al. Characteristics, sources, and health risks of PM2.5-bound trace elements in representative areas of Northern Zhejiang Province, China. Chemosphere. 2021;272:129632. doi:10.1016/j.chemosphere.2021.129632	No effect size calculation
Zona A, Fazzo L, Benedetti M, et al. SENTIERI - Studio epidemiologico nazionale dei territori e degli insediamenti esposti a rischio da inquinamento. Sesto Rapporto. Epidemiol Prev. 2023;47(1-2 Suppl 1):1-286. doi:10.19191/EP23.1-2-S1.003.	Wrong exposure
Zona A, Iavarone I, Buzzoni C, et al. SENTIERI: Studio epidemiologico nazionale dei territori e degli insediamenti esposti a rischio da inquinamento. Quinto Rapporto. Epidemiol Prev. 2019;43(2-3 Suppl 1):1-170. doi:10.19191/EP19.2-3.S1.032.	Wrong exposure

Table S4. Additional criteria used for the risk-of-bias assessment.

Domain	Study type	Criteria considered
Confounding	Long-term	Critical confounders: age, sex, socioeconomic status, and smoking, where relevant to the outcome. Other/additional confounders: calendar year or year of enrolment/death, occupational exposure, and body mass index.
Confounding	Short-term	Critical confounders: temperature, seasonality, day of the week, long-term time trends, holidays, and influenza epidemics, particularly for respiratory outcomes and mortality. Other/additional confounders: relative humidity and other meteorological variables, when relevant.
Exposure assessment	Short-term	The judgement focused on whether daily pollutant concentrations adequately captured temporal variations in exposure in the study population.
Exposure assessment	Long-term	The judgement focused on whether the exposure method adequately captured spatial contrasts in long-term exposure between individuals or areas.
Other risk-of-bias domains	All study types	Domains and reporting questions provided by the WHO Risk of Bias Assessment Instrument.

Table S5. Main characteristics of the included studies.

Study ID*	First Author (year)	Area	Study Design	Study Population	Age of Enrolment	Study Period	Outcome Domain	Population[2]	Total Events[2]
L1	Bauleo 2019	Civitavecchia (Italy)	Cohort	Resident	18+	1996-2013	All-cause/Specific mortality	71 362	13 687
L2	Fano 2004	Civitavecchia (Italy)	Case–Control	Resident	-	1987-1995	Specific mortality	963	234
L3	Kioumourtzoglou 2015	United States	Cohort	Resident	65+	2000-2010	All-cause mortality	19 274 534	6 383 358
L4	Li 2022	Yancheng (China)	Cohort	Newborns	-	2013-2017	Specific incidence	58 713	8159
L5	Matos 2022	Ponta da Praia & Boqueirão (Brazil)	Cross-sectional	Resident	18-59	2016	Specific incidence	220	25
L6	Paolocci 2020	Civitavecchia (Italy)	Cohort	Resident	35-69	2013-2016	Specific incidence	1141	728
L7	Al Okla 2024	Oman	Cross-Sectional	Asthma patients	0-50	2014-2022	Specific incidence	264	210

S1	Liu 2022	Zhoushan city (China)	Time Series	Pediatric residents	0-18	2014-2020	Specific hospitalizations	142 825	NA
S2	Gianicolo 2013	Brindisi (Italy)	Case-crossover	Resident	NA	2001-2007	Specific hospitalizations	90 000	108 372
S3	Mentz 2018	Durban (South Africa)	Panel	Asthmatic children	7-14	2017	Specific incidence	423	74 260
S4	Ji 2021	Qingdao (China)	Time Series	Schizophrenic patients	NA	2015-2019	Specific re-hospitalizations	NA	6220
S5	Liu 2018	China	Time Series	Resident	NA	2015-2016	Specific hospitalizations	NA	4026-26 653
S6	Psistaki 2023	Greece and Cyprus	Time Series	Resident	NA	1999-2016	All-cause/Specific mortality	258 900-1 110 551	21 740-73 600
S7	Tian 2013	Hong Kong (China)	Time Series	Resident	NA	1998-2007	Specific hospitalizations	NA	562 408
S8	Willers 2016	Rotterdam (Netherlands)	Case-crossover	Resident	NA	1995-2009	All-cause/Specific mortality	600 000	73 178

S9	Yang 2022	Qingdao (China)	Time Series	Resident	15+	2014-2018	Specific visits	NA	23 870
S10	Yoo 2019	South Korea	Time Series	Resident	NA	2013-2015	All-cause/Specific mortality	NA	2 866-53 872
S11	Abd Rahim 2024	Klang (Malaysia)	Time Series	Resident	NA	2011-2019	Specific hospitalizations	1.07 million	59 681
S12	Su 2025	California	Panel	Asthmatic or COPD patients	NA	2012-2019	Specific incidence	1992	161 by day

Information not reported in the original studies was treated as missing, and no assumptions or imputations were made to replace unavailable data. *ID prefix: L = long-term; S = short-term. [2]Where more than one cohort was analysed a min-max range was reported.

Table S6. Overview of exposure assessment approaches across included studies

Study ID	**Exposure assessment approach**	**Temporal scale**	**Meteorological and geographical factors considered**	**Spatial assignment**	**Source attribution**
L1	Dispersion modelling and residential proximity	Annual, time-invariant	Meteorology, turbulence and orography in dispersion modelling	Residential address; 500 m grid	Industrial/traffic-specific; harbour proxy
L2	Residential history and proximity	Historical exposure window	Residential distance to harbour and industrial sources; meteorology not explicitly assessed	Individual residential history	Harbour/industrial proxies

L3	Fixed-site monitoring and $PM_{2.5}$ composition	Annual, time-varying	No explicit meteorological exposure modelling	City-level	Chemical composition proxies
L4	Fixed-site monitoring	Pregnancy-specific averages	Season of conception; sea breeze discussed only	Nearest residential monitor	None
L5	Fixed-site monitoring and area comparison	Daily	Temperature and humidity adjustment; neighbourhood comparison	Neighbourhood-level	Port-area proxy
L6	Source-specific dispersion modelling	Annual, time-invariant	Meteorological and terrain-related conditions in SPRAY modelling	Residential address; 500 m grid	Industrial, shipping, traffic and biomass
L7	Residential proximity	Time-invariant	Industrial proximity; wind direction discussed but not quantitatively assessed	Distance-based exposure zones	Port/industrial proxies
S1	Fixed-site monitoring	Daily	Temperature, humidity, atmospheric pressure and seasonal analyses	City-level	None
S2	Fixed-site monitoring; reconstructed PM_{10}	Daily	Temperature and humidity adjustment; prevailing wind-direction effect modification	City-level	Wind-sector effect modification
S3	School-based and municipal monitoring	Daily	Wind, rainfall, pressure, temperature and vertical temperature difference in exposure-data imputation	Area-level (north/south)	Industrial-area proxy

S4	Fixed-site monitoring	Daily	Temperature and humidity adjustment	City-level	None
S5	Fixed-site monitoring	Daily	Temperature, humidity and wind speed adjustment; coastal–inland comparison	City-level	None
S6	Fixed-site monitoring	Daily	Temperature, humidity, seasonal analyses and dust-storm identification	City-level	None
S7	PM_{10} chemical speciation	Intermittent 24-h sampling	Temperature and humidity adjustment	City-level	Chemical tracers (Ni, V)
S8	Dispersion modelling and monitoring	Daily	Temperature, humidity, wind and radiation in thermal exposure modelling; neighbourhood contrasts	Neighbourhood-level	Traffic-informed ambient model
S9	Fixed-site monitoring	Daily	Temperature, humidity and seasonal trends	City-level	None
S10	$PM_{2.5}$ chemical speciation	Intermittent 24-h sampling	Temperature and humidity adjustment; seasonal pollution patterns	City-level	Chemical tracers (Ni, V)
S11	Continuous fixed-site monitoring	Daily	Temperature and humidity adjustment	District-level	None

S12	Source-specific STILT modelling	Monthly	Meteorological inputs in STILT modelling; temperature and humidity adjustment	GPS-based locations; census tract centroids	Combined port-craft and railway emissions

"None" indicates no explicit source attribution, not absence of emissions from identifiable sources. Chemical tracers and proximity indicators provide indirect source information. For S2, wind direction was evaluated as an effect modifier rather than used to quantitatively apportion pollutant concentrations.

Table S7. Study quality assessment, according to the risk-of-bias assessment instrument for systematic reviews informing WHO global air quality guidelines

First Author (year)	Confounding	Selection Bias	Exposure Assessment	Outcome Measurement	Missing Data	Selective Reporting	Overall
Bauleo 2019	High	Low	Moderate	Low	Low	Low	High
Fano 2004	Moderate	Low	High	Low	Low	Low	High
Kioumourtzoglou 2015	Low	Low	Moderate	Low	Low	Low	Moderate
Li 2022	High	Low	Moderate	Low	Low	Low	High
Matos 2022	Moderate	Low	High	Low	High	Low	High
Paolocci 2020	Moderate	Low	Low	Low	Low	Low	Moderate
Al Okla 2024	High	Low	High	Low	Low	Low	High
Liu 2022	High	Low	Low	Low	Low	Low	High
Gianicolo 2013	High	Moderate	Moderate	Low	Low	Low	High
Mentz 2018	Moderate	High	Low	Low	Low	Low	High
Ji 2021	Low	High	Low	Low	Low	Low	High
Liu 2018	High	Low	Low	Low	Low	Low	High
Psistaki 2023	Low	Low	Moderate	Low	Low	Low	Moderate
Tian 2013	High	Low	Moderate	Low	Low	Low	High
Willers 2016	Low	Low	Low	Low	Low	Low	Low
Yang 2022	High	Low	Low	Low	Low	Low	High
Yoo 2019	High	High	Moderate	Low	Low	Low	High

Abd Rahim 2024	High	Low	Moderate	Low	Low	Low	High
Su 2025	High	Low	Low	Low	Low	Low	High

Table S8. Study-specific justifications for risk-of-bias judgements

First Author (year)	Confounding	Selection Bias	Exposure Assessment	Outcome Measurement	Missing Data	Selective Reporting
Bauleo 2019	H: Individual smoking data unavailable	L: Population-based residential cohort	M: lack of a validation study with in situ measurements	L: Official mortality registry	L: Registry-based follow-up	L: Analyses and outcomes reported
Fano 2004	M: Smoking and occupational histories obtained from relatives	L: Matched controls; high response rates	H: Residential distance from sources used as exposure proxy	L: ICD-coded lung cancer mortality	L: Limited nonresponse	L: Planned analyses reported
Kioumourtzoglou 2015	L: Extensive adjustment and city-specific models	L: Defined Medicare cohort	M: City-level exposure measurements	L: Mortality from administrative records	L: Longitudinal administrative follow-up	L: Analyses and outcomes reported
Li 2022	H: Maternal smoking not controlled	L: Prospective maternal cohort	M: Fixed-site exposure assigned throughout pregnancy	L: Birthweight-based outcome definition	L: Routine maternal health records	L: Analyses and outcomes reported
Matos 2022	M: Individual confounders omitted from pollutant models	L: Systematic neighborhood sampling	H: Area-level pollutant concentrations	L: Standardized ECRHS questionnaire	H: Missing-data handling not documented	L: Analyses and outcomes reported
Paolocci 2020	M: Historical occupational exposure incompletely assessed	L: Random sampling from municipal registers	L: Source-specific dispersion modelling	L: Standardized spirometry and questionnaires	L: Available examination data analysed	L: Analyses and outcomes reported

Al Okla 2024	H: Critical confounders not jointly adjusted	L: Defined clinical eligibility criteria	H: Distance-based exposure zones	L: Physician assessment using GINA criteria	L: Incomplete records excluded	L: Analyses and outcomes reported
Liu 2022	H: Holidays and influenza activity not controlled	L: Routine paediatric outpatient records	L: Daily monitoring data	L: Recorded outpatient visits	L: Routine healthcare data	L: Analyses and outcomes reported
Gianicolo 2013	H: Temporal trends not adequately controlled	M: Admissions restricted to local hospitals	M: Limited monitoring network; one NO2 station	L: Hospital diagnoses identified through standard ICD codes	L: Administrative admission records	L: Analyses and outcomes reported
Mentz 2018	M: Daily meteorological confounders not explicitly adjusted	H: Selected schools and enrichment of asthmatic children	L: Intensive school-based pollution monitoring	L: Validated respiratory symptom diaries	L: Missing observations mainly due to school absence	L: Analyses and outcomes reported
Ji 2021	L: Temporal and meteorological confounders controlled	H: Readmissions captured at one psychiatric hospital	L: Daily measurements from eight stations	L: Clinician-assigned ICD-10 diagnoses	L: Hospital records used	L: Analyses and outcomes reported
Liu 2018	H: Holidays and influenza activity not controlled	L: Routine multicity hospitalization data	L: Daily regulatory monitoring	L: Recorded COPD admissions	L: Hospitalization data routinely collected	L: Analyses and outcomes reported
Psistaki 2023	L: Temporal trends and meteorological factors controlled	L: Official population mortality records	M: Fixed-site exposure assignment	L: Official ICD-coded mortality records	L: Missing pollution data addressed	L: Analyses and outcomes reported
Tian 2013	H: Potential confounding by influenza, holiday and day of the week	L: Territory-wide emergency admission records	M: Citywide averaging of component concentrations	L: Official hospital admission records	L: Available monitoring days documented	L: Analyses and outcomes reported
Willers 2016	L: Time-matched case-	L: Population-based	L: High-resolution exposure modelling	L: Official mortality registry	L: Registry-based outcome	L: Analyses and outcomes reported

	crossover design	mortality data			ascertainment	
Yang 2022	H: Holidays, day of the week and influenza activity not controlled	L: Routine pneumonia hospitalization records	L: Daily monitoring data	L: Hospital-recorded pneumonia visits	L: Routine hospital data	L: Single- and multi-pollutant results reported
Yoo 2019	H: Holidays and influenza activity not explicitly controlled	H: Cities and monitors selected by data availability	M: One PM-component monitoring site per city	L: Official ICD-coded death certificates	L: Incomplete monitoring series excluded	L: Analyses and outcomes reported
Abd Rahim 2024	H: Influenza activity not controlled	L: Defined hospital admission population	M: Fixed-site exposure measurements	L: ICD-coded cardiovascular admissions	L: Routine hospital records	L: Analyses and outcomes reported
Su 2025	H: Long-term trends, weekdays, holidays and influenza not controlled	L: Defined digital-sensor cohort	L: Geolocated source-specific dispersion modelling	L: Sensor-recorded rescue inhaler use	L: Missing locations addressed through imputation	L: Analyses and outcomes reported

H = High; M = Moderate; L = Low

Table S9 Main pollutant information of the included studies.

Study ID*	Period air pollutant mean concentration[1]							
	PM_{10} ($\mu g/m^3$)	**$PM_{2.5}$ ($\mu g/m^3$)**	**PMc ($\mu g/m^3$)**	**NO_2 ($\mu g/m^3$)**	**NO ($\mu g/m^3$)**	**O_3 ($\mu g/m^3$)**	**CO (mg/m^3)**	**SO_2 ($\mu g/m^3$)**
L1	-	-	-	-	-	-	-	-
L2	-	-	-	-	-	-	-	-
L3	-	12.8	-	-	-	-	-	-
L4	78.47	45.12	-	24.29	-	78.86	0.76	16.33
L5	-	-	-	-	-	32.28-41.20	-	-
L6	-	-	-	-	-	-	-	-
L7	-	-	-	-	-	-	-	-
S1	43.32	24.89	-	19.55	-	94.55	0.64	6.8
S2	26.10	-	-	28.70	-	-	-	-
S3	47.7-51.8	-	-	10.9-17.2	22.1-40.9	-	-	1.9-8.7
S4	82.43	41.33	41.10	34.47	-	-	0.75	16.23
S5	64.3-128.0	35.3-60.4	-	-	-	-	-	15.4-43.4
S6	45.5-47.3	18.3-27.8	-	34.7-53.2	15.4-57.0	46.4-48.8	-	4.1-12.8
S7	54.7	-	-	58.0	-	39.8	-	19.5
S8[2]	31.8	-	-	38.3	-	42.0	-	-
S9	86.4	43.3	-	34.6	-	101.7	0.8	20.4
S10	-	22.3-27.1	-	-	-	-	-	-
S11	76.07	61.59	-	70.18	-	89.28	1.91	13.82
S12	-	-	-	-	-	-	-	-

*ID prefix: L = long-term; S = short-term. **S8 Use median value. [1]Where more than one cohort was analysed, a min-max range was reported.

Table S10. Main source-specific pollutant information of the included studies.

Study ID*	Period source-specific air pollutant mean concentration					
	PM_{10} Industrial source ($\mu g/m^3$)	**PM_{10} Port-related source ($\mu g/m3$)**	**PM_{10} Biomass combustion ($\mu g/m^3$)**	**$PM_{2.5}$ ($\mu g/m^3$) Portual and locomotive source**	**NO_2 (ppb) Portual and locomotive source**	**NOx Traffic source ($\mu g/m^3$)**
L1	4.49	-	-	-	-	5.80
L6	0.03	0.02	9.59	-	-	6.32
S12	-	-	-	4.308	8.472	-

*ID prefix: L = long-term; S = short-term.