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# BMJ Open

## Arson at an urban solid waste landfill in Italy: effects on human reproductive health

Journal:	<i>BMJ Open</i>
Manuscript ID	bmjopen-2018-027912
Article Type:	Research
Date Submitted by the Author:	14-Nov-2018
Complete List of Authors:	<p>MAZZUCCO, WALTER; University of Palermo, Scienze Promozione Salute e Materno Infantile; Palermo University Hospital "P. Giaccone", Clinical Epidemiology and Cancer Registry Unit</p> <p>Tavormina, Elisa; Regional Health Authority, Department of Health Services and Epidemiological Observatory</p> <p>Macaluso, M; Cincinnati Children's Hospital Medical Center, Division of Biostatistics and Epidemiology; University of Cincinnati College of Medicine, Department of Pediatrics</p> <p>Marotta, Claudia; University of Palermo, Sciences for health promotion (PROSAMI) Department</p> <p>Cusimano, Rosanna; Palermo University Hospital "P. Giaccone", Clinical Epidemiology and Cancer Registry Unit</p> <p>Alba, Davide; University of Palermo, Sciences for health promotion (PROSAMI) Department</p> <p>Costantino, Claudio; University of Palermo, Sciences for health promotion (PROSAMI) Department</p> <p>Grammauta, Rosario; National Research Council, Istituto per l'Ambiente Marino Costiero (IAMC) "Capo Granitola",</p> <p>Cernigliaro, Achille; Regional Health Authority, Department of Health Services and Epidemiological Observatory</p> <p>Scondotto, Salvatore; Regional Health Authority, Department of Health Services and Epidemiological Observatory</p> <p>Vitale, Francesco; University of Palermo, Department of Sciences for Health Promotion "G. D'Alessandro" – Hygiene section; Palermo University Hospital "P. Giaccone", Clinical Epidemiology and Cancer Registry Unit</p>
Keywords:	PUBLIC HEALTH, Maternal medicine < OBSTETRICS, Enviromental health

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Manuscripts

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3 1 **Title page**  
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5 2 **Title:** Arson at an urban solid waste landfill in Italy: effects on human reproductive health.  
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8 3  
9  
10 4 **Authors**  
11

12 5 Walter Mazzucco\* <sup>a,b</sup>, Elisa Tavormina <sup>c</sup>, Maurizio Macaluso\* <sup>d</sup>, Claudia Marotta <sup>a</sup>, Rosanna  
13  
14 6 Cusimano <sup>f</sup>, Davide Alba <sup>a</sup>, Claudio Costantino <sup>a</sup>, Rosario Grammauta <sup>g</sup>, Achille Cernigliaro <sup>c</sup>,  
15  
16  
17 7 Salvatore Scondotto <sup>c</sup>, Francesco Vitale <sup>a,b</sup>.  
18

19 8 \*These authors contributed equally.  
20  
21

22 9  
23  
24 10 <sup>a</sup> Sciences for health promotion (PROSAMI) Department, University of Palermo, Palermo, Italy  
25

26 11 <sup>b</sup> Clinical Epidemiology and Cancer Registry Unit, Palermo University Hospital "P. Giaccone",  
27  
28 12 Palermo, Italy  
29

30 13 <sup>c</sup> Department of Health Services and Epidemiological Observatory, Regional Health Authority,  
31  
32 14 Sicilian Region, Palermo, Italy  
33

34  
35 15 <sup>d</sup> Division of Biostatistics and Epidemiology, Cincinnati Children's Hospital Medical Center, and  
36  
37 16 Department of Pediatrics, University of Cincinnati College of Medicine, Cincinnati, OH, USA  
38

39  
40 17 <sup>f</sup> Palermo Health Agency, Palermo, Italy  
41

42 18 <sup>g</sup> Istituto per l'Ambiente Marino Costiero (IAMC) "Capo Granitola", National Research Council,  
43  
44 19 Via del Mare 3, 91021 Torretta Granitola, TP, Italy  
45  
46

47 20  
48  
49 21 Corresponding author:  
50

51 22 Claudia Marotta, Dipartimento Scienze Promozione della Salute e Materno Infantile "G.  
52  
53 23 D'Alessandro", Università degli Studi di Palermo. Via del Vespro, 133 - 90127 Palermo, Italy  
54

55  
56 24 Telephone number: +393337984116 Fax: +390916553631  
57

58 25 E-mail: marotta.claudia@gmail.com  
59

60 26 **Word count:** 2.783

## 27 Abstract

28 **Objectives:** In response to increasing public health concern raising from the occurrence of arson in  
29 solid waste management plants in July 2012, a longitudinal retrospective study was performed  
30 using vital statistics data to evaluate any potential effect on pregnancies at different gestational ages  
31 of pollutants emitted from the landfill on fire.

32 **Setting:** Community, in particular a population resident nearby a landfill plant.

33  
34 **Participants:** The study group comprised all live births and stillbirths to mothers residing within  
35 the exposed areas and conceived during a 40 weeks period intercepting the highest peak of the fire.

36 **Primary and secondary outcome measures:** Birth outcomes (gestational age <37 weeks, low birth  
37 weight, very low birth weight and small for gestational age) in the study group were compared to  
38 the birth outcomes of a reference group of women residing in areas of Sicily with similarly low  
39 population density and industrial development.

40 **Results:** There was a statistically significant excess of low birth weight singleton infants in the  
41 study group as compared to the reference group, which was limited to births to mothers exposed  
42 during peri-conception period (OR adjusted for maternal age= 4.64; 95%CI= 1.04 – 20.6) and first  
43 trimester (OR adjusted for maternal age= 3.66; 95%CI= 1.11 – 12.1).

44 **Conclusions:** The study documented an excess of very low birth weight in newborns to mothers  
45 who were exposed to the landfill fire emissions during conception or early pregnancy.

## 46 Summary

### 47 Strengths and limitations of this study

- 48 • In response to increasing public health concern raising from the occurrence of arson in solid  
49 waste management plants, we investigated the potential health effects of short term exposure  
50 to pollutants emitted from the waste on fire.
- 51 • We documented a statistically significant association between pregnancy exposure to  
52 emissions spread by urban waste landfill on fire and an excess of low birth weight singleton

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3 53 infants. In particular, our findings highlighted that mothers exposed during peri-conception  
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5 54 and first trimester of pregnancy represent a high-risk group.

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8 55 • The study adds to the growing body of evidence that exposure to high concentration of  
9  
10 56 pollutants emitted from solid waste landfill may have serious health effects and underscores  
11  
12 57 the need for monitoring potential hazards and health outcomes in the population resident  
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14 58 nearby the landfill plants.
- 15  
16  
17 59 • The retrospective design and the analysis of data from vital statistics do not allow a detailed  
18  
19 60 assessment of the longitudinal nature of the exposure-response relation, nor a precise  
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21 61 adjustment for potential confounding.
- 22  
23  
24 62 • As it is often the case in studies of local environmental exposure events, the outcomes of  
25  
26 63 interest were limited in number, especially when stratified according to the stage of the  
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28 64 pregnancy at exposure.

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31 65  
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33 66 **Key words:** exposure to air pollutant; landfill emissions; low birth-weight; conception; early  
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35 67 pregnancy.

## 36 37 38 68 39 40 69 **Introduction**

41  
42 70 The number of studies investigating the potential human health effects on communities of pollutants  
43  
44 71 released from landfills or incinerators is increasing,[1,2] showing that exposure is weakly associated  
45  
46 72 with a variety of adverse health outcomes, including cancer, adverse reproductive outcomes and  
47  
48 73 birth defects.[3-5] Increased risk of low birth weight and congenital malformations has been  
49  
50 74 reported in communities living in proximity to landfills.[2,6] Maternal exposure to incinerator  
51  
52 75 emissions was associated with preterm delivery.[7] A study of exposure to incinerator emissions  
53  
54 76 containing dioxin concluded that exposure had little impact on birth weight and sex ratio, but may  
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56 77 have been associated with gestational age at delivery.[8] Inconsistent findings across studies may  
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58 78 be due to design issues, lack of exposure information, use of indirect surrogate measures, acute

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3 79 versus long-term exposure conditions, and inadequate control of confounding.[9] Variation in risk  
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5 80 perception among the stakeholders makes it difficult to communicate about the available evidence.  
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8 81 In Italy, the incidence of fires in solid waste management plants is increasing,[10] addressing the  
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10 82 need to investigate the potential health effects of short-term exposure to pollutants emitted from the  
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12 83 combustion of solid waste.

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14 84 In Sicily, the fourth most populated Italian region, 5 million residents produce about 6,000 tons of  
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17 85 solid waste daily, which are disposed of in 4 Municipal Solid Waste Landfills (MSW-L).[11] The  
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19 86 largest MSW-L is located in Bellolampo at 450 meters above sea level, on the hidden side of a  
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21 87 mountain at the south-western border of Palermo (the largest city in Sicily, with 700,000  
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24 88 inhabitants, and its administrative capital).[11] The Bellolampo MSW-L collects solid waste from  
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26 89 the Palermo metropolitan area, which includes the city and nearby municipalities.[12] On July 29,  
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28 90 2012, a fire started at multiple points within the landfill and emissions spread from the entire  
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30 91 structure to a large populated area, becoming a threat of Public Health concern. Emissions peaked  
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33 92 in the first 24 hours and decreased thereafter, until the fire was fully extinguished by August 16,  
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35 93 2012.

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37 94 We analyzed vital statistics data to retrospectively evaluate the potential effects of the arson on the  
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40 95 outcomes of pregnancies that were exposed to the emissions at different gestational ages.  
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## 43 44 97 **Methods**

45  
46 98 In response to the arson, the Sicilian Regional Health Authority defined an area of 10 km radius  
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49 99 around the landfill, whose resident population was considered as potentially exposed to the MSW-L  
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51 100 emissions and placed under surveillance (**Supplementary File**).[13] Environmental monitoring of  
52  
53 101 the area [14] was done through existing stationary monitoring stations.[15] A longitudinal  
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56 102 retrospective study was designed to study the effects of exposure to the fire emissions on  
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58 103 reproductive health outcomes. The study included all live births and stillbirths to mothers residing  
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60 104 within the surveillance zone, whose estimated conception date occurred from 36 weeks prior to the

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3 105 peak of the fire (from 2:00PM on July 29, 2012 to 2:00PM on July 30, 2012), until 4 weeks after the  
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5 106 fire. Births were identified through the regional Certificate of Birth Attendance (CedAP) registry.  
6  
7 107 The CedAP registry maintains data on all births to women of childbearing age (10-55 years old)  
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9 108 who delivered in Sicily, including parental socio-demographic characteristics, obstetric history,  
10  
11 109 prenatal care, and characteristics of pregnancy and birth. The registry does not include data on  
12  
13 110 births to resident mothers who delivered outside the region (data not available) or wanted to  
14  
15 111 preserve anonymity (0,4%). Date of conception was estimated using the date of birth and  
16  
17 112 gestational age at birth reported in the registry.  
18  
19 113 To remove confounding by exposure to pollutants deriving from anthropic activities and vehicular  
20  
21 114 traffic within metropolitan areas, we restricted the main focus of the analysis to residents of the  
22  
23 115 extra-urban section of the surveillance area (**Supplementary File**). Thus, the study group included  
24  
25 116 births in the extra-urban surveillance area from pregnancies that were potentially exposed to the fire  
26  
27 117 around the time of conception as well as pregnancies that were exposed at later stages (through the  
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29 118 36<sup>th</sup> week). The reference group comprised all live births and stillbirths to mothers residing in the  
30  
31 119 remaining extra-urban, low-density and unindustrialized areas of Sicily, during the same time  
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33 120 interval.  
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35 121 To distinguish pregnancy periods of susceptibility to acute exposure to the fire emissions, the  
36  
37 122 proportions defined above were computed separately for strata defined according to four sub-  
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39 123 periods of exposure, corresponding to i) peri-conception (conception occurring between the  
40  
41 124 beginning of the landfill fire and up to 4 weeks later), ii) first trimester (conception date 12-0 weeks  
42  
43 125 before the fire), iii) second trimester (24-13 weeks before), and iv) third trimester (36-25 weeks  
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45 126 before) (**Figure 1**). For each stage of the pregnancy at the time of exposure, we compared birth  
46  
47 127 outcomes of the study group with those of the reference group. We also conducted internal  
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49 128 comparisons of stages of pregnancy at the time of exposure within the study group.  
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51 129 We conducted two secondary analyses: first, we compared birth outcomes to mothers in the  
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53 130 metropolitan area of Palermo (the main metropolitan area served by the Bellolampo MSW-L,

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131 656,829 inhabitants) with those to mothers residing in the two other Sicilian metropolitan areas of  
132 Catania (293,104 inhabitants) and Messina (242,914 inhabitants) in the same study period. Second,  
133 to assess any systematic difference between the study group and the reference group independently  
134 from the fire, we repeated the comparison using data on births that occurred during the year  
135 preceding the arson (specifically, births conceived within -36 and +4 weeks from July 29, 2011).  
136 Using the information available from CedAP registry, we followed European guidelines for  
137 perinatal statistics adopted by the PERISTAT system[16, 17] and evaluated the following  
138 proportions among all births (i.e., live births and stillbirths combined): proportion of stillbirths,  
139 proportions of male and female births, and proportions of singleton and multiple births. We  
140 evaluated the following proportions among live births: preterm birth (gestational age <37 weeks),  
141 low birth weight (<2,500 grams), very low birth weight (<1,500 grams) and small for gestational  
142 age (SGA) (birth weight under the tenth percentile of the national distribution of birth weights of  
143 the same gestational age or birth of gestational age  $\geq 37$  weeks weighing <2,500 grams).  
144 To make statistical inference about the comparisons between the different study groups and the  
145 references, we used logistic regression to estimate odds ratios (OR) and 95% confidence intervals  
146 (CI) of the ORs. ORs were adjusted by maternal age and newborn sex for comparisons based on all  
147 births, and by maternal age for comparisons based on singleton live births.  
148 Statistical analyses were carried out by using STATA (version 11.2 MP, StataCorp, College Station,  
149 TX). STROBE guidelines were followed for research reporting.

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### 150 **Patient and Public Involvement**

151 Patients were not involved.

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### 154 **Results**

155 During the interval of interest (11/20/2011-08/26/2012) there were a total of 551 births (548 live  
156 births + 3 stillbirths) from pregnancies to mothers residing in the exposed extra-urban area (the



1  
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3 157 study group) and 22,341 births (22,264 live births + 65 stillbirths) from pregnancies to mothers  
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5 158 residing in the remaining Sicilian low population-density, low industrialization areas (the  
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8 159 comparison group). Among all births, there was a statistically no significant twofold excess of  
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10 160 stillbirths in the extra-urban group (OR adjusted by gender=1.89; 95%CI = 0.59-6.03), while among  
11  
12 161 singleton live births there was a two-fold, statistically significant risk excess for very low birth  
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15 162 weight (OR adjusted for maternal age= 2.20; 95%CI= 1.02 - 4.72) (**Table 1**).

16  
17 163 **Table 1.** Outcomes of 4,653 births from pregnancies to mothers residing in the Palermo  
18 164 metropolitan area and of 3,980 births from pregnancies to Sicilian women residing in the remaining  
19 165 metropolitan areas (comparison group), that were estimated to be conceived within -36 and +4  
20 166 weeks from July 29, 2012.  
21  
22 167

Birth outcome	Palermo exposed Metropolitan Area	Remaining Metropolitan Areas (Catania and Messina)	Unadjusted OR		Adjusted OR	
	N (%)	N (%)	OR	(95%CI)	OR*	(95%CI)
<b>All Births</b>	4,653 (100)	3,980 (100)	<b>OR</b>	<b>(95%CI)</b>	<b>OR*</b>	<b>(95%CI)</b>
<b>Gender</b>						
Male	2,350 (50.51)	2,040 (51.26)	1 (ref.)		1 (ref.)	
Female	2,303 (49.49)	1,940 (48.74)	1.03	(0.94 – 1.12)	1.03	(0.94 – 1.12)
<b>Plurality</b>						
Singleton birth	4,492 (96.54)	3,829 (96.21)	1 (ref.)		1 (ref.)	
Multiple birth	161 (3.46)	151 (3.79)	0.91	(0.72 - 1.14)	0.91	(0.72 - 1.14)
<b>Status at birth</b>						
<b>Live births</b>	4,636 (99.63)	3,966 (99.65)	1 (ref.)		1 (ref.)	
<b>Stillbirths</b>	17 (0.37)	14 (0.35)	1.04	(0.51 - 2.11)	1.03	(0.51 - 2.10)
<b>Singleton live births</b>	4,492 (100)	3,829 (100)	<b>OR</b>	<b>(95%CI)</b>	<b>OR**</b>	<b>(95%CI)</b>
<b>Pre-term</b> ( $<37$ weeks)	169 (7.25)	111 (6.75)	1.08	(0.84 - 1.38)	1.08	(0.84 - 1.39)
<b>Low birth weight</b> ( $<2.500$ gr)	146 (6.74)	180 (7.15)	0.86	(0.69 - 1.08)	0.86	(0.69 - 1.08)
<b>Very low birth weight</b> ( $<1500$ gr)	25 (1.07)	21 (0.83)	1.28	(0.72 - 2.30)	1.28	(0.72 - 2.30)
<b>Small for gestational age</b>	59 (2.53)	66 (4.01)	0.62	(0.43 - 0.89)	0.62	(0.64 – 1.77)

\*OR adjusted for infant gender; \*\*OR adjusted for maternal age

57 183 Among all births, there were statistically significant differences between the study group and the  
58  
59 184 comparison group that were limited to births whose pregnancies were in the third trimester when  
60

the fire began: a twofold excess of multiple births (OR adjusted by gender= 2.42; 95%CI= 1.38-4.24) and a fourfold excess of stillbirths (OR adjusted by gender= 4.69; 95%CI= 1.40-15.6) were documented (Table 2). Among singleton live births there were statistically significant differences in very low birth weight rates between the extra-urban area and the remaining Sicilian low inhabitants density and unindustrialized areas for births whose pregnancies were either in peri-conception period (OR adjusted for maternal age= 4.64; 95%CI= 1.04 – 20.6) or in the first trimester (OR adjusted for maternal age= 3.66; 95%CI= 1.11 – 12.1) when the fire began (Table 2).

**Table 2.** Outcomes of 551 births from pregnancies to mothers residing in the extra-urban area and of 22,342 births from pregnancies to Sicilian women residing in low inhabitants density and unindustrialized areas (comparison group), that were estimated to be conceived within -36 and +4 weeks from July 29, 2012.

Birth outcome	Extra-urban exposed area	Comparison group	Unadjusted OR		Adjusted OR	
	N (%)	N (%)				
<b>All Births</b>	551 (100)	22,342 (100)	<b>OR</b>	<b>(95%CI)</b>	<b>OR**</b>	<b>(95%CI)</b>
<b>Gender</b>		7 (0,03)*				
Male	299 (54.26)	11,464 (51.31)	1 (ref.)		1 (ref.)	
Female	252 (45.74)	10,871 (48.66)	0.89	(0.75 - 1.05)	0.89	(0.75 - 1.05)
<b>Plurality</b>						
Singleton birth	530 (96.19)	21,594 (96.65)	1 (ref.)		1 (ref.)	
Multiple birth	21 (3.81)	748 (3.35)	1.14	(0.73 - 1.78)	1.17	(0.75 - 1.82)
<b>Status at birth</b>		13 (0,06)*				
<b>Live births</b>	548 (99.46)	22,264 (99.65)	1 (ref.)		1 (ref.)	
<b>Stillbirths</b>	3 (0.54)	65 (0.29)	1.88	(0.59 - 5.98)	1.89	(0.59 - 6.03)
<b>Singleton live births</b>	530 (100)	21,525 (100)	<b>OR</b>	<b>(95%CI)</b>	<b>OR***</b>	<b>(95%CI)</b>
<b>Pre-term (&lt;37 weeks)</b>	36 (6.82)	1,094 (5.13)	1.35	(0.96 - 1.91)	1.35	(0.96 - 1.90)
<b>Low birth weight (&lt;2.500 gr)</b>	37 (6.99)	1,143 (5.31)	1.34	(0.95 - 1.88)	1.36	(0.97 - 1.91)
<b>Very low birth weight (&lt;1500 gr)</b>	7 (1.32)	131 (0.61)	<b>2.19</b>	<b>(1.02 - 4.71)</b>	<b>2.20</b>	<b>(1.02 - 4.72)</b>
<b>Small for gestational age</b>	15 (2.84)	578 (2.71)	1.05	(0.62 - 1.76)	1.07	(0.65 – 1.80)

\*Number and percentage of non-missing values \*\*OR adjusted for infant gender; \*\*\*OR adjusted for maternal age

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200 Internal comparisons of the susceptibility period within the extra-urban exposed group did not  
201 reveal statistically significant differences between subgroups defined by stages of the pregnancy at  
202 the time of exposure, but these comparisons were hampered by the small size of the study group  
203 (results not shown).

204 Our secondary analyses did not show any significant differences in the outcomes of 4,653 births to  
205 mothers residing in the Palermo metropolitan area which were conceived during the time interval  
206 within -36 and +4 weeks from July 29, 2012 and 3,980 births to mothers residing in the other  
207 Sicilian metropolitan areas during the same time interval (**Table 3**), or in the outcomes of births  
208 from pregnancies to mothers residing in the extra-urban exposed area and births from pregnancies  
209 to Sicilian women residing in low population-density, low-industrialization areas of Sicily,  
210 conceived within -36 and +4 weeks from July 29, 2011 (one year before the arson) (**Table 4**).

**Table 3.** Outcomes of births from pregnancies to mothers residing in the exposed extra-urban area and of births from pregnancies to Sicilian women residing in low inhabitants density and unindustrialized are (comparison groups) by susceptibility sub-periods.

Birth outcome	Pregnancy stage as of the beginning of the fire (July 29, 2012)											
	Peri-conception			I Trimester (12-0 weeks)			II Trimester (24-13 weeks)			III Trimester (36-25 weeks)		
	Extra-urban exposed area	Comparison Group	OR** (95%CI)	Extra-urban exposed area	Comparison Group	OR** (95%CI)	Extra-urban exposed area	Comparison Group	OR** (95%CI)	Extra-urban exposed area	Comparison Group	OR** (95%CI)
	N (%)*	N (%)		N (%)	N (%)		N (%)*	N (%)*		N (%)	N (%)	
<b>All Births</b>	42 (100)	2,051 (100)		144 (100)	6,000 (100)		173 (100)	6,757 (100)		187 (100)	7,352 (100)	
<b>Gender</b>												
Male	27 (64)	1,054 (51)	1 (ref.) 0.59 (0.31-1.11)	82 (57)	3,129 (52)	1 (ref.) 0.82 (0.59-1.15)	88 (51)	3,430 (51)	1 (ref.) 0.99 (0.74-1.35)	101 (54)	3,755 (51)	1 (ref.) 0.89 (0.67-1.19)
Female	15 (36)	997 (49)		62 (43)	2,870 (48)		85 (49)	3,327(49)		86 (46)	3,591(49)	
<b>Plurality</b>												
Singleton birth	42 (100)	1993 (97)	1 (ref.)	142 (99)	5,793 (97)	1 (ref.) 0.4 (0.09-1.62)	168 (97)	6,535 (97)	1 (ref.) 0.89 (0.36-2.18)	173 (93)	7,099 (97)	1 (ref.) <b>2.42</b> <b>(1.38-4.24)</b>
Multiple birth	0 (0.0)	58 (2.8)	0 (-)	2 (1.4)	97 (3.4)		5 (2.9)	222 (3.3)		14 (7.5)	253 (3.4)	
<b>Status at birth</b>												
Live births	42 (100)	2,046 (99.8)	1 (ref.)	144 (100)	5,989 (99.8)	1 (ref.)	173 (100)	6,730 (99.7)	1 (ref.)	184 (98.4)	7,318 (99.54)	1 (ref.) <b>4.69</b> <b>(1.40-15.6)</b>
Stillbirths	0(0.0)	5 (0.2)	0 (-)	0(0.0)	10 (0.2)	0 (-)	0(0.0)	23 (0.34)	0 (-)	3 (1.6)	26 (0.35)	
<b>Singleton live births</b>	42 (100)	1,983 (100)	<b>OR*** (95%CI)</b>	142 (100)	5,788 (100)	<b>OR*** (95%CI)</b>	168 (100)	6,435 (100)	<b>OR*** (95%CI)</b>	172 (100)	7,075 (100)	<b>OR*** (95%CI)</b>
<b>Pre-term</b>												
(<37 weeks)	36 (7.14)	94 (4.81)	1.46 (0.44-4.83)	11(7.75)	295 (5.16)	1.52 (0.81-2.85)	11 (6.55)	352 (5.47)	1.21 (0.65-2.26)	11 (6.43)	343 (4.88)	1.35 (0.73-2.51)
<b>Low birth weight(&lt;2500g)</b>	2 (4.76)	116 (5.85)	0.83 (0.20-3.48)	12 (8.45)	327 (5.65)	1.57 (0.86-2.88)	11 (6.55)	353 (5.42)	1.22 (0.66-2.27)	12 (6.98)	341 (4.82)	1.52 (0.83-2.76)
<b>Very low birth weight(&lt;1500g)</b>	2 (4.76)	20 (1.01)	<b>4.64</b> <b>(1.04-20.6)</b>	3 (2.11)	34 (0.59)	<b>3.66</b> <b>(1.11-12.1)</b>	0 (0.0)	37 (0.57)	0 (-)	2 (1.16)	39 (0.55)	2.18 (0.52-9.12)
<b>Small for gestational age</b>	0 (0.0)	61 (3.1)	0 (-)	4 (2.82)	167 (2.92)	1.00 (0.36-2.74)	5 (2.98)	173 (2.69)	1.11 (0.45-2.75)	6 (3.51)	175 (2.49)	1.45 (0.63-3.31)

\*Number and percentage of non-missing values; \*\*OR adjusted for infant gender; \*\*\*OR adjusted for maternal age

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**Table 4.** Outcome of 536 births from pregnancies to mothers residing in the exposed extra-urban area and of 23,373 births from pregnancies to Sicilian women residing in low inhabitants density and unindustrialized areas of Sicily (comparison group), that were estimated to be conceived within -36 and +4 weeks from July 29, 2011 (in last year before the arson).

Birth outcome	Extra-urban exposed area	Comparison group	Unadjusted OR		Adjusted OR	
	N (%)	N (%)	OR	(95%CI)	OR*	(95%CI)
<b>All Births</b>	536 (100)	23,373 (100)				
<b>Gender</b>						
Male	272 (50.75)	12,041 (51.52)	1 (ref.)		1 (ref.)	
Female	264 (49.25)	11,329 (48.57)	1.03	(0.87 - 1.22)	1.03	(0.87 - 1.22)
<b>Plurality</b>						
Singleton birth	520 (97.01)	22,632 (96.83)	1 (ref.)		1 (ref.)	
Multiple birth	16 (2.99)	741 (3.17)	0.94	(0.57 - 1.56)	0.96	(0.58 - 1.58)
<b>Status at birth</b>						
<b>Live births</b>	534 (99.63)	23,291 (99.65)	1 (ref.)		1 (ref.)	
<b>Stillbirths</b>	2 (0.37)	79 (0.34)	1.10	(0.27 - 4.50)	1.10	(0.27 - 4.50)
			<b>OR</b>	<b>(95%CI)</b>	<b>OR**</b>	<b>(95%CI)</b>
<b>Pre-term (&lt;37 weeks)</b>	30 (5.78)	1,226 (5.44)	1.06	(0.731 - 1.54)	1.07	(0.74 - 1.55)
<b>Low birth weight (&lt;2.500 gr)</b>	35 (6.74)	1,226 (5.44)	1.26	(0.88 - 1.78)	1.26	(0.89 - 1.79)
<b>Very low birth weight (&lt;1500 gr)</b>	4 (0.77)	133 (0.59)	1.31	(0.48 - 3.55)	1.31	(0.48 - 3.56)
<b>Small for gestational age</b>	15 (2.89)	616 (2.75)	1.05	(0.62 - 1.77)	1.05	(0.63- 1.77)

\*OR adjusted for infant gender; \*\*OR adjusted for maternal age

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## Discussion

This retrospective study investigated birth outcomes among women residing near one of the largest Italian solid waste landfills (the Bellolampo MSW-L), who were pregnant during a fire that started on July 29, 2012 and lasted for about a two-week period before being completely extinguished. The population potentially affected by the emissions comprising women residing both in metropolitan and low population-density, low-industrialization areas of Sicily, who were pregnant during the same time interval. As we were not able to estimate the impact of confounding by exposure to pollutants deriving from anthropic activities and vehicular traffic for the metropolitan areas, our

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244 primary analysis focused on the potential impact of the fire on births to mothers residing in the  
245 extra-urban area adjacent to the landfill. As compared to births occurring during the same interval  
246 to mothers residing in other areas of Sicily with similar population density and level of  
247 industrialization, we observed a statistically significant differences suggesting that the landfill arson  
248 could have had an adverse impact on pregnancy outcomes. Our secondary analysis did not  
249 highlight statistically significant differences between the metropolitan exposed area and the other  
250 metropolitan populations in Sicily. In the study group, the analysis documented a two-fold,  
251 statistically significant excess risk of very low birth weight (<1500g) among singleton live births.  
252 The effect appeared to be concentrated among births whose conception date was between 12 weeks  
253 prior to the beginning of the fire to 4 weeks after, indicating that the largest impact of the exposure  
254 may have been on pregnancies that were conceived during the fire (OR adjusted for maternal age=  
255 4.64; 95%CI= 1.04 – 20.6) or were exposed to the fire during the first trimester (OR adjusted for  
256 maternal age= 3.66; 95%CI= 1.11 – 12.1). As this type of outcome is typically associated with very  
257 early pre-term birth (gestational age <32 weeks), these findings are compatible with a toxic effect  
258 on placentation or early embryo development leading to premature delivery.[18,19] Maternal  
259 exposure to ambient concentrations of air pollutants, particularly to fine particulate matter, has been  
260 identified as a risk factor for preterm birth, low birth weight and SGA births.[20] Multiple studies  
261 have documented an association between fine particulate exposure and preterm birth.[21-23]  
262 Exposure to wildfires has been proposed as a risk factor for preterm birth [20] and reduced average  
263 birth weight.[24, 25]  
264 In a multi-site Italian study, maternal exposure to incinerator emissions was associated with preterm  
265 delivery even at very low levels.[7] Moreover, a study conducted in Taiwan concluded that  
266 exposure to emissions from an incinerator generating dioxin had little effects on birth weight and  
267 female birth, but may have a modest effect on gestational age.[8]  
268 The mechanisms proposed to explain the effect of fine particulate exposure on preterm birth include  
269 oxidative stress, pulmonary and placental inflammation, coagulopathy, endothelial dysfunction and

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3 270 hemodynamic responses,[20, 26] as well as intrauterine inflammation.[20] Of interest, adverse  
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5 271 pregnancy outcomes including pre-term delivery, intrauterine growth restriction and impaired infant  
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8 272 weight gain are associated with exposure to polychlorinateddibenzo-p-dioxins (PCDDs),  
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10 273 polychlorinated dibenzofurans (PCDFs) and dioxin-like PCBs (DL-PCBs).[1] Recently, The  
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12 274 Hokkaido Study on Environment and Children's Health has demonstrated the effects of  
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15 275 environmental chemical exposures (dioxins, polychlorinated biphenyls, organochlorine pesticides,  
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17 276 perfluoroalkyl substances, phthalates, bisphenol A, and methylmercury) on genetically susceptible  
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19 277 populations and on DNA methylation,[28] while other research suggests that exposure to  
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22 278 tetrachlorodibenzo-*p*-dioxin (TCDD) may induce shifts in the immune response that enhance a  
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24 279 proinflammatory phenotype at the maternal-fetal interface, increasing the risk of infection-mediated  
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26 280 preterm birth.[29]  
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29 281 The body of published evidence, taken together with the statistically significant excess risk  
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31 282 concentrated in a relatively narrow period of susceptibility, lends credibility to the hypothesis that  
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33 283 the Bellolampo arson adversely affected pregnancies exposed during conception or in the first  
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35 284 trimester, causing an excess of deliveries of very low birth weight infants in the extra-urban area.  
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38 285 The study also documented in the same area a significant four-fold excess of stillbirths among  
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40 286 pregnancies that were exposed to the landfill fire during the third trimester. This finding is based on  
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42 287 a total of three stillbirths that occurred in the extra-urban study group, all of which were  
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45 288 concentrated to the subgroup exposed during the third trimester, and it is possible that the observed  
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47 289 excess is due to chance even if it was statistically significant. On the other hand, long-term  
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49 290 exposure to PCBs was associated with increased proportions of miscarriage and stillbirth in animal  
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52 291 studies,[30] and exposure to emissions from solid-waste incinerators was associated with increased  
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54 292 risk of miscarriage in an epidemiologic study in Italy.[31] Thus, the excess of stillbirths to mothers  
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56 293 exposed during the third trimester could be causally related to the arson.  
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59 294 The excess of multiple births from pregnancies exposed during the third trimester in the study group  
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295 is unlikely to be caused by exposure to the landfill fire, as plurality must have been established long

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296 before the arson. The literature provides conflicting evidence on the association between exposure  
297 to air pollution from incinerators and multiple births.[32]

298 Long-term exposure of the study area to pollutants (independently from the fire) was already known  
299 and was confirmed by the detection of TCCD and heavy metals at concentrations above the limits  
300 permitted by law [33] in sub-soil samples collected by the regional environment protection agency  
301 after the fire.[34] However, the secondary analysis comparing birth outcomes in the same extra-  
302 urban groups in the year before the arson did not highlight any potential effect related to a long-  
303 term exposure to pollutants emitted from the landfill.

304 The findings of this study should be interpreted in light of some limitations. First, the retrospective  
305 design and the analysis of data from vital statistics do not allow a detailed assessment of the  
306 longitudinal nature of the exposure-response relation, or precise adjustment for potential  
307 confounding. Although environmental monitoring was performed in response to the arson, we had  
308 limited access to the data and could only confirm the increase in air particulate concentrations after  
309 the beginning of the fire. Thus, we could not assess specific exposure levels of individual  
310 pregnancies at multiple points in time. Lastly, as it is often the case in studies of local  
311 environmental exposure events, the outcomes of interest were limited in number, especially when  
312 stratified according to the stage of the pregnancy at exposure. Nevertheless, the observations made  
313 in this study are of general interest. While previous studies conducted in Italy have suggested  
314 associations between exposure to incinerator emissions and increased risk of miscarriages and  
315 preterm births,[31] to our knowledge, the present study is the first in Europe to investigate the  
316 effects of exposure emissions on birth outcomes evaluating pregnancies exposed at different stages  
317 of development. Despite the limited information base and sample size, the excess of very low birth  
318 weight infants achieved statistical significance and was confined to early-stage pregnancies.

319 The study adds to the growing body of evidence that exposure to emissions from solid waste  
320 landfill operations may have serious health effects and underscores the need for monitoring  
321 potential hazards and health outcomes in the resident population.[35] The arsons at the Bellolampo



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3 322 MSW-L,[36] as well as the ones that occurred in other Italian solid waste treatment plants in  
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5 323 proximity to populated areas,[10] and the public concern they caused, exemplify the important role  
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7 324 that integration of environmental monitoring and epidemiologic surveillance may have in this  
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10 325 realm.[37-39] The questionable strength of the evidence collected in this and in similar studies also  
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12 326 underscores the need for better planning of monitoring and surveillance activities (more detailed  
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14 327 exposure information, better definition and monitoring of reproductive and other health outcomes,  
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17 328 assessment of long-term effects and better control for potential confounders), and highlights the  
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19 329 difficulty of conveying results to the various stakeholders [9] and the related need for effective  
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21 330 methods to transfer study results to policy makers and the public.[40]

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24 331 Finally, our study highlights the importance to promote an integrated management of urban solid  
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26 332 waste alternatives to landfills, including waste to energy plants or other newly available  
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28 333 technologies such as pyrolysis and gasification.[41]

### 30 334 **Ethics**

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33 335 Ethical approval was obtained by the “Palermo Ethical Committee 1” on February 14, 2018  
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35 336 (protocol number: 02/2018).

### 37 337 **Data sharing**

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40 338 No additional data available.

### 42 339 **Funding**

43  
44  
45 340 No funding received.

### 47 341 **Competing interests**

48  
49 342 The authors declare they have no actual or potential competing interests.

### 51 343 **Authors’ contributions**

52  
53 344 All individuals listed as authors have contributed substantially to designing, performing or reporting  
54  
55 345 the study and every specific contribution is indicated as follows. Conception and design of the  
56  
57  
58 346 study: WM, MM, RC, AC. Data collection: ET, AC, SS. Statistical analysis: ET, AC, RG, MM,  
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60 347 WM. Interpretation of data: CC, CM, WM, MM, AC, ET. Manuscript writing and drafting: WM,

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348 MM, CM, AC, DA. Revision of the manuscript: WM, CM, MM, SS, FV. Approval of the final  
349 version of the manuscript: WM, ET, MM, CM, RC, DA, CC, RG, AC, SS, FV.

### 350 **Acknowledgments**

351 The authors are grateful to the Regional Environmental Protection Agency of Sicily (ARPA Sicilia)  
352 for technical assistance with the study design.

For peer review only

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3 467 **Figure 1.** Area potentially exposed to emissions deriving from the Bellolampo municipal solid  
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5 468 waste landfill: **a)** Under surveillance area; **b)** Metropolitan area (Palermo) and extra-urban area (in  
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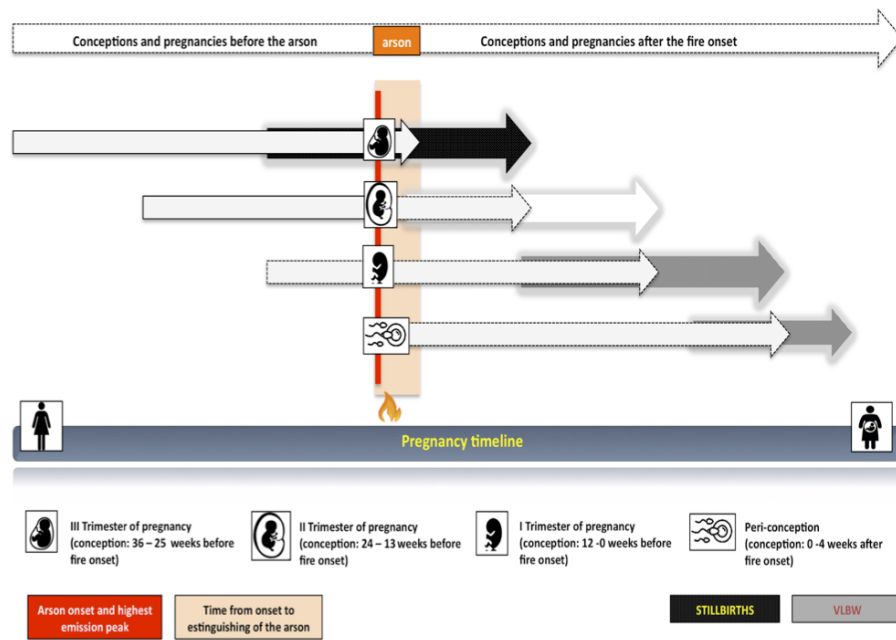
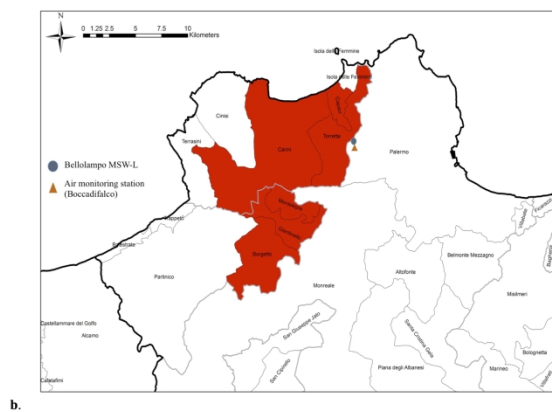
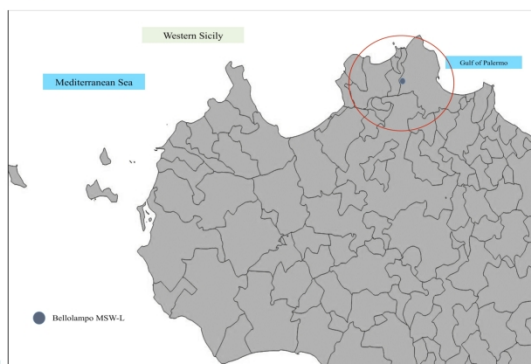


Figure 1. Area potentially exposed to emissions deriving from the Bellolampo municipal solid waste landfill:  
 a) Under surveillance area; b) Metropolitan area (Palermo) and extra-urban area (in red).

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**Supplementary file.** Area potentially exposed to emissions deriving from the Bellolampo municipal solid waste landfill: **a)** Under surveillance area; **b)** Metropolitan area (Palermo) and extra-urban area (in red).



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## STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4 - 6
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	4-6
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6
Bias	9	Describe any efforts to address potential sources of bias	5
Study size	10	Explain how the study size was arrived at	4
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5-6
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	5-6
		(b) Describe any methods used to examine subgroups and interactions	5-6
		(c) Explain how missing data were addressed	NA
		(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	NA
		(e) Describe any sensitivity analyses	NA

Continued on next page

<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6-7
		(b) Give reasons for non-participation at each stage	NA
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6
		(b) Indicate number of participants with missing data for each variable of interest	NA
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	7-9
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	NA
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	NA
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	7-9
		(b) Report category boundaries when continuous variables were categorized	9-11
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	11-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13
Generalisability	21	Discuss the generalisability (external validity) of the study results	15
<b>Other information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15

\*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).

# BMJ Open

## Do emissions from landfill fires affect pregnancy outcomes? A retrospective study after arson at a solid waste facility in Sicily.

Journal:	<i>BMJ Open</i>
Manuscript ID	bmjopen-2018-027912.R1
Article Type:	Research
Date Submitted by the Author:	21-May-2019
Complete List of Authors:	MAZZUCCO, WALTER; University of Palermo, Scienze Promozione Salute e Materno Infantile; Palermo University Hospital "P. Giaccone", Clinical Epidemiology and Cancer Registry Unit Tavormina, Elisa; Regional Health Authority, Department of Health Services and Epidemiological Observatory Macaluso, M; Cincinnati Children's Hospital Medical Center, Division of Biostatistics and Epidemiology; University of Cincinnati College of Medicine, Department of Pediatrics Marotta, Claudia; University of Palermo, Sciences for health promotion (PROSAMI) Department Cusimano, Rosanna; Palermo University Hospital "P. Giaccone", Clinical Epidemiology and Cancer Registry Unit Alba, Davide; University of Palermo, Sciences for health promotion (PROSAMI) Department Costantino, Claudio; University of Palermo, Sciences for health promotion (PROSAMI) Department Grammauta, Rosario; National Research Council, Istituto per l'Ambiente Marino Costiero (IAMC) "Capo Granitola", Cernigliaro, Achille; Regional Health Authority, Department of Health Services and Epidemiological Observatory Scondotto, Salvatore; Regional Health Authority, Department of Health Services and Epidemiological Observatory Vitale, Francesco; University of Palermo, Department of Sciences for Health Promotion "G. D'Alessandro" – Hygiene section; Palermo University Hospital "P. Giaccone", Clinical Epidemiology and Cancer Registry Unit
<b>Primary Subject Heading</b>:	Epidemiology
Secondary Subject Heading:	Reproductive medicine
Keywords:	PUBLIC HEALTH, Maternal medicine < OBSTETRICS, Enviromental health, exposure to air pollutant

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3 1 **Title page**  
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5 2 **Title:** Do emissions from landfill fires affect pregnancy outcomes? A retrospective study after arson  
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8 3 at a solid waste facility in Sicily.  
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10 4  
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12 5 **Authors**  
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14 6 Walter Mazzucco\* <sup>a,b</sup>, Elisa Tavormina <sup>c</sup>, Maurizio Macaluso\* <sup>d</sup>, Claudia Marotta <sup>a</sup>, Rosanna  
15  
16  
17 7 Cusimano <sup>f</sup>, Davide Alba <sup>a</sup>, Claudio Costantino <sup>a</sup>, Rosario Grammata <sup>g</sup>, Achille Cernigliaro <sup>c</sup>,  
18  
19 8 Salvatore Scondotto <sup>c</sup>, Francesco Vitale <sup>a,b</sup>.

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21 9 \*These authors contributed equally.  
22  
23

24 10  
25  
26 11 <sup>a</sup> Sciences for health promotion (PROSAMI) Department, University of Palermo, Palermo, Italy  
27

28 12 <sup>b</sup> Clinical Epidemiology and Cancer Registry Unit, Palermo University Hospital "P. Giaccone",  
29  
30 13 Palermo, Italy  
31

32  
33 14 <sup>c</sup> Department of Health Services and Epidemiological Observatory, Regional Health Authority,  
34  
35 15 Sicilian Region, Palermo, Italy  
36

37 16 <sup>d</sup> Division of Biostatistics and Epidemiology, Cincinnati Children's Hospital Medical Center, and  
38  
39 17 Department of Pediatrics, University of Cincinnati College of Medicine, Cincinnati, OH, USA  
40

41  
42 18 <sup>f</sup> Palermo Health Agency, Palermo, Italy  
43

44 19 <sup>g</sup> Istituto per l'Ambiente Marino Costiero (IAMC) "Capo Granitola", National Research Council,  
45  
46 20 Via del Mare 3, 91021 Torretta Granitola, TP, Italy  
47  
48

49 21  
50  
51 22 Corresponding author:  
52

53 23 Claudia Marotta, Dipartimento Scienze Promozione della Salute e Materno Infantile "G.  
54

55  
56 24 D'Alessandro", Università degli Studi di Palermo. Via del Vespro, 133 - 90127 Palermo, Italy  
57

58 25 Telephone number: +393337984116 Fax: +390916553631  
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60 26 E-mail: marotta.claudia@gmail.com

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3 27 **Word count:** 2.783  
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5 28 **Abstract**  
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7 29 **Objectives:** In response to public health concern about effects of arson at solid waste management  
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10 30 plants in July 2012, we analysed vital statistics data to evaluate any potential effect on pregnancies  
11  
12 31 at different gestational ages of pollutants emitted from the landfill on fire.  
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14 32 **Setting:** A community living near the largest landfill plant in Sicily.  
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17 34 **Participants:** The study group comprised 551 births live births and stillbirths from pregnancies of  
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19 35 mothers residing in the extra-urban exposed area, conceived during a 40-week period during which  
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21 36 the highest fire's peak might have influenced pregnancy.  
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24 37 **Primary and secondary outcome measures:** Birth outcomes (gestational age <37 and <32 weeks,  
25  
26 38 low birth weight, very low birth weight and small for gestational age) in the study group were  
27  
28 39 compared to the ones of a reference group of women residing in areas of Sicily with similarly low  
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30 40 population density and industrial development.  
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33 41 **Results:** Among singleton live births we observed a three-fold increase in risk of very preterm birth  
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35 42 between the extra-urban area and the remaining low inhabitants density and unindustrialized areas  
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37 43 for births whose pregnancies were in the third trimester (OR adjusted for maternal age and infant  
38  
39 44 gender= 3.41; 95%CI= 1.04 - 11.16). There was an excess of very low birth weight singleton  
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41 45 infants in the study group as compared to the reference group, which was limited to births to  
42  
43 46 mothers exposed during peri-conception period (OR adjusted for maternal age and infant gender=  
44  
45 47 4.64; 95%CI= 1.04 – 20.6) and first trimester (OR adjusted for maternal age and infant gender =  
46  
47 48 3.66; 95%CI= 1.11 – 12.1). The association estimates were imprecise due to the small number of  
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49 49 outcomes recorded.  
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53 50 **Conclusions:** The study documented an excess of very preterm and very low birth weight among  
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55 51 infants born to mothers exposed to the landfill fire emissions during conception or early pregnancy.  
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58 52 **Strengths and limitations of this study**  
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3 53 • Vital statistics were used to investigate the potential reproductive health effects of short term  
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5 54 exposure to pollutants emitted from an arson at an urban solid waste facility.  
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8 55 • The study documented the effects of the emissions from urban solid waste management  
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10 56 plant on birth outcomes evaluating pregnancies exposed at different stages of development.  
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12 57 • The study added to the growing body of evidence that exposure to pollutants emitted from  
13  
14 58 solid waste landfills may have serious health effects and underscores the need for  
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16 59 monitoring potential hazards and health outcomes in the population living near landfills.  
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19 60 • The retrospective design and the limited vital statistics data available for analysis did not  
20  
21 61 allow a detailed assessment of the longitudinal nature of the exposure-response relation, nor  
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23 62 a precise adjustment for potential confounding.  
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26 63 • As it is often the case in studies of local environmental exposure events, the number of  
27  
28 64 relevant outcomes was limited, especially when stratified according to the stage of the  
29  
30 65 pregnancy at exposure, and association estimates were imprecise.  
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35 67 **Key words:** exposure to air pollutant; landfill emissions; low birth-weight; conception; early  
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37 pregnancy.  
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## 43 70 **Introduction**

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45 71 The number of studies investigating the potential human health effects on communities of pollutants  
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47 72 released from landfills or incinerators is increasing,[1,2] showing that exposure is weakly associated  
48  
49 73 with a variety of adverse health outcomes, including cancer, adverse reproductive outcomes and  
50  
51 74 birth defects.[3-5] Increased risk of low birth weight and congenital malformations has been  
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53 75 reported in communities living in proximity to landfills.[2,6] Maternal exposure to incinerator  
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55 76 emissions was associated with preterm delivery.[7] A study of exposure to incinerator emissions  
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57 77 containing dioxin concluded that exposure had little impact on birth weight and sex ratio, but may  
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59 78 have been associated with gestational age at delivery.[8] Inconsistent findings across studies may  
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3 79 be due to design issues, lack of exposure information, use of indirect surrogate measures, acute  
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5 80 versus long-term exposure conditions, and inadequate control of confounding.[9] Variation in risk  
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7 81 perception among the stakeholders makes it difficult to communicate about the available evidence.  
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10 82 In Italy, the incidence of fires in solid waste management plants is increasing,[10] addressing the  
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12 83 need to investigate the potential health effects of short-term exposure to pollutants emitted from the  
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14 84 combustion of solid waste.  
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17 85 In Sicily, the fourth most populated Italian region, 5 million residents produce about 6,000 tons of  
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19 86 solid waste daily, which are disposed of in 4 Municipal Solid Waste Landfills (MSW-L).[11] The  
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21 87 largest MSW-L is located in Bellolampo at 450 meters above sea level, on the hidden side of a  
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23 88 mountain at the south-western border of Palermo (the largest city in Sicily, with 700,000  
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25 89 inhabitants, and its administrative capital).[11] The Bellolampo MSW-L collects solid waste from  
26  
27 90 the Palermo metropolitan area, which includes the city and nearby municipalities.[12] On July 29,  
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29 91 2012, a fire started at multiple points within the landfill and emissions spread to a large populated  
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31 92 area, causing concern for the public's health. Emissions peaked in the first 24 hours and decreased  
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33 93 thereafter, until the fire was fully extinguished by August 16, 2012.  
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37 94 We analyzed vital statistics data to retrospectively evaluate the potential effects of the arson on the  
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39 95 outcomes of pregnancies that were exposed to the emissions at different gestational ages.  
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## 44 97 **Methods**

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47 98 In response to the arson, the Sicilian Regional Health Authority defined an administrative area  
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49 99 around the landfill, whose resident population was considered as potentially exposed to the MSW-L  
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51 100 emissions and placed under surveillance (**Supplementary file**).[13] Environmental monitoring of  
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53 101 the area [14] was done through existing stationary monitoring stations.[15] A longitudinal  
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55 102 retrospective study was designed to study the effects of exposure to the fire emissions on  
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57 103 reproductive health outcomes. We obtained limited data from the regional Certificate of Birth  
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59 104 Attendance (CedAP) registry, which collects information on all births to women of childbearing age  
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3 105 (10-55 years old) who deliver in Sicily, including parental socio-demographic characteristics,  
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5 106 obstetric history, prenatal care, and characteristics of pregnancy and birth. The CedAP registry does  
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8 107 not include data on births to resident mothers who delivered outside the region or wanted to  
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10 108 preserve anonymity (0.4%). Date of conception was estimated using the date of birth and  
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12 109 gestational age at birth reported in the registry. The study included all live births and stillbirths to  
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15 110 mothers residing within the surveillance zone, whose estimated conception date occurred from 36  
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17 111 weeks prior to the peak of the fire (from 2:00PM on July 29, 2012 to 2:00PM on July 30, 2012),  
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19 112 until 4 weeks after the fire. To remove confounding by exposure to pollutants deriving from  
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22 113 anthropic activities and vehicular traffic within metropolitan areas, we restricted the main focus of  
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24 114 the analysis to residents of the extra-urban section of the surveillance area (**Supplementary file**).  
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26 115 Thus, the study group included all live births and stillbirths in the extra-urban surveillance area  
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28 116 from pregnancies that were potentially exposed to the fire around the time of conception as well as  
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31 117 pregnancies that were exposed at later stages (through the 36<sup>th</sup> week). The reference group  
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33 118 comprised all live births and stillbirths to mothers residing in the remaining extra-urban, low-  
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35 119 density and unindustrialized areas of Sicily, during the same time interval. To distinguish pregnancy  
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38 120 periods of susceptibility to acute exposure to the fire emissions, we stratified the study group and  
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40 121 the reference population according to the following four sub-periods of exposure (**Figure 1**):  
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42 122 i) peri-conception (conception occurring on July 29, 2012 or up to 4 weeks later);  
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44 123 ii) first trimester (conception date 12-0 weeks before July 29, 2012);  
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47 124 iii) second trimester (24-13 weeks before July 29, 2012);  
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49 125 iv) third trimester (36-25 weeks before July 29, 2012).  
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51 126 For each stage of the pregnancy at the time of exposure, we compared birth outcomes of the study  
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54 127 group with those of the reference group. We also carried out internal comparisons within the study  
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56 128 group, contrasting outcomes across the four sub-periods of exposure.  
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58 129 We conducted two supplementary analyses: first, we compared birth outcomes to mothers in the  
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60 130 metropolitan area of Palermo (the main metropolitan area served by the Bellolampo MSW-L,

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3 131 656,829 inhabitants) with those to mothers residing in the two other Sicilian metropolitan areas  
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5 132 (Catania, 293,104 inhabitants, and Messina, 242,914 inhabitants) in the same study period. Second,  
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8 133 to assess any systematic difference between the study group and the reference group independently  
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10 134 from the fire, we repeated the comparison using data on births that occurred during the year  
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12 135 preceding the arson (specifically, births conceived within -36 and +4 weeks from July 29, 2011).  
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15 136 For each comparison, we evaluated the following proportions, defined according to European  
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17 137 guidelines for perinatal statistics adopted by the PERISTAT system[16,17]: a) among all births (i.e.,  
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19 138 live births and stillbirths combined): proportion of stillbirths, proportions of male and female births,  
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22 139 and proportions of singleton and multiple births; b) among live births: preterm birth (gestational age  
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24 140 <37 weeks), very preterm birth (gestational age <32 weeks), low birth weight (<2,500 grams), very  
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26 141 low birth weight (<1,500 grams) and small for gestational age (SGA) (birth weight under the tenth  
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28 142 percentile of the national distribution of birth weights of the same gestational age or birth of  
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31 143 gestational age  $\geq 37$  weeks weighing <2,500 grams).  
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33 144 Because of CedAP data flow at the time in study was relatively new, we were only able to use the  
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35 145 limited information described in this manuscript.  
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38 146 To make statistical inference about the comparisons between the different study groups and the  
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40 147 references, we used logistic regression to estimate odds ratios (OR) and 95% confidence intervals  
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42 148 (CI) of the ORs, with and without adjusting for maternal age and infant gender, the only two  
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45 149 potential confounders made available to us. Throughout this paper we treated the OR as an estimate  
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47 150 of the risk ratio. This is appropriate as the absolute risks for most of the outcomes considered are  
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49 151 well below 10%, and under these conditions the OR closely approximates the RR. Statistical  
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51 152 analyses were carried out using STATA (version 11.2 MP, StataCorp, College Station, TX).  
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54 153 STROBE guidelines were followed for research reporting.

## 56 154 **Patient and Public Involvement**

58 155 Patients were not involved.  
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## 157 Results

158 Mothers residing in the exposed extra-urban area (the study group) gave birth to a total of 551  
 159 infants (548 live born + 3 stillborn) conceived during the interval of interest (11/20/2011-  
 160 08/26/2012). There were 22,341 births (22,264 live births + 65 stillbirths) from pregnancies  
 161 conceived during the same period by mothers residing in the remaining Sicilian low population-  
 162 density, low industrialization areas (the comparison group). We observed a two-fold increase in risk  
 163 of very preterm birth (OR adjusted for maternal age and infant gender= 2.29; 95%CI= 1.12 - 4.68)  
 164 and a two-fold increase in risk of very low birth weight (OR adjusted for maternal age and infant  
 165 gender= 2.20; 95%CI= 1.02 - 4.72) among singleton live births (**Table 1**).

166 **Table 1.** Outcomes of 551 births from pregnancies to mothers residing in the extra-urban area  
 167 (study group) and of 22,342 births from pregnancies to Sicilian women residing in similar low  
 168 population density, low industrialization areas (comparison group), conceived between 36 weeks  
 169 before and 4 weeks after July 29, 2012.

Birth outcome	Extra-urban exposed area	Comparison group	Unadjusted OR		Adjusted OR	
	N (%)	N (%)				
<b>All Births</b>	551 (100)	22,342 (100)	<b>OR</b>	<b>(95%CI)</b>	<b>OR**</b>	<b>(95%CI)</b>
<b>Gender</b>		7 (0,03)*				
Male	299 (54.26)	11,464 (51.31)	1 (ref.)		1 (ref.)	
Female	252 (45.74)	10,871 (48.66)	0.89	(0.75 - 1.05)	0.8	(0.75 - 1.05)
<b>Plurality</b>						
Singleton birth	530 (96.19)	21,594 (96.65)	1 (ref.)		1 (ref.)	
Multiple birth	21 (3.81)	748 (3.35)	1.14	(0.73 - 1.78)	1.17	(0.75 - 1.82)
<b>Status at birth</b>		13 (0,06)*				
<b>Live births</b>	548 (99.46)	22,264 (99.65)	1 (ref.)		1 (ref.)	
<b>Stillbirths</b>	3 (0.54)	65 (0.29)	1.88	(0.59 - 5.98)	1.89	(0.59 - 6.03)
<b>Singleton live births</b>	530 (100)	21,525 (100)	<b>OR</b>	<b>(95%CI)</b>	<b>OR**</b>	<b>(95%CI)</b>
<b>Preterm</b> (<37 weeks)	36 (6.82)	1,094 (5.13)	1.35	(0.96 - 1.91)	1.35	(0.96 - 1.90)
<b>Very preterm</b> (<32 weeks)	8 (1.52)	144 (0.68)	<b>2.26</b>	<b>(1.10 - 4.63)</b>	<b>2.29</b>	<b>(1.12 - 4.68)</b>
<b>Low birth weight</b> (<2.500 gr)	37 (6.99)	1,143 (5.31)	1.34	(0.95 - 1.88)	1.36	(0.97 - 1.91)
<b>Very low birth weight</b> (<1500 gr)	7 (1.32)	131 (0.61)	<b>2.19</b>	<b>(1.02 - 4.71)</b>	<b>2.20</b>	<b>(1.02- 4.72)</b>
<b>Small for gestational age</b>	15 (2.84)	578 (2.71)	1.05	(0.62 - 1.76)	1.07	(0.65 - 1.80)

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*Number and percentage of non-missing values **OR adjusted for maternal age and infant gender (OR contrasting male and female gender adjusted for maternal age, only)
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g all births, we observed differences between the study group and the comparison group that were limited to births whose pregnancies were in the third trimester when the fire began: a twofold excess of multiple births (OR adjusted by gender= 2.42; 95%CI= 1.38-4.24) and a fourfold excess of stillbirths (OR adjusted by gender= 4.69; 95%CI= 1.40-15.6) (**Table 2**).

Among singleton live births we observed a three-fold increase in risk of very preterm between the extra-urban area and the remaining Sicilian low inhabitants density and unindustrialized areas for births whose pregnancies were in the third trimester (OR adjusted for maternal age and infant gender= 3.41; 95%CI= 1.04 - 11.16) when the fire began (**Table 2**).

Among singleton live births there were differences in very low birth weight rates between the extra-urban area and the remaining Sicilian low inhabitants density and unindustrialized areas for births whose pregnancies were either in peri-conception period (OR adjusted for maternal age and infant gender= 4.64; 95%CI= 1.04 – 20.6) or in the first trimester (OR adjusted for maternal age and infant gender= 3.66; 95%CI= 1.11 – 12.1) when the fire began (**Table 2**). Additional analyses of the risk of very low birth weight stratified by gestational age revealed that the excess of very low birth weight overlapped only in part with very preterm birth: remarkably, the infants accounting for the excess of very low birth weight from pregnancies conceived around the time of exposure were born after 32 weeks of gestation (results not shown in detail). Internal comparisons of the susceptibility period within the extra-urban exposed group did not reveal clear differences between subgroups defined by stages of the pregnancy at the time of exposure, but these comparisons were hampered by the small size of the study group (results not shown).

Our supplementary analyses did not show differences between the outcomes of 4,653 births to mothers residing in the Palermo metropolitan area which were conceived between 36 weeks before and 4 weeks after July 29, 2012 and the outcomes of 3,980 births to mothers residing in the other Sicilian metropolitan areas conceived during the same time interval (**Table 3**). Similarly, we

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196 observed no differences between the outcomes of births from pregnancies to mothers residing in the  
197 extra-urban exposed area and the outcomes of births from pregnancies to Sicilian women residing in  
198 low population-density, low-industrialization areas of Sicily, conceived between 36 weeks before  
199 and 4 weeks after July 29, 2011 (one year before the arson) (**Table 4**).

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**Table 2.** Outcomes of births from pregnancies to mothers residing in the exposed extra-urban area and of births from pregnancies to Sicilian women residing in similar low population density, low industrialization areas (comparison groups) by susceptibility sub-periods.

Birth outcome	Pregnancy stage as of the beginning of the fire (July 29, 2012)											
	Peri-conception			I Trimester (12-0 weeks)			II Trimester (24-13 weeks)			III Trimester (36-25 weeks)		
	Extra-urban exposed area	Comparison Group	OR** (95%CI)	Extra-urban exposed area	Comparison Group	OR** (95%CI)	Extra-urban exposed area	Comparison Group	OR** (95%CI)	Extra-urban exposed area	Comparison Group	OR** (95%CI)
	N (%)*	N (%)		N (%)	N (%)		N (%)*	N (%)*		N (%)	N (%)	
<b>All Births</b>	42 (100)	2,051 (100)		144 (100)	6,000 (100)		173 (100)	6,757 (100)		187 (100)	7,352 (100)	
<b>Gender</b>												
Male	27 (64)	1,054 (51)	1 (ref.) 0.59 (0.31-1.11)	82 (57)	3,129 (52)	1 (ref.) 0.82 (0.59-1.15)	88 (51)	3,430 (51)	1 (ref.) 0.99 (0.74-1.35)	101 (54)	3,755 (51)	1 (ref.) 0.89 (0.67-1.19)
Female	15 (36)	997 (49)		62 (43)	2,870 (48)		85 (49)	3,327(49)		86 (46)	3,591(49)	
<b>Plurality</b>												
Singleton birth	42 (100)	1993 (97)	1 (ref.)	142 (99)	5,793 (97)	1 (ref.) 0.4 (0.09-1.62)	168 (97)	6,535 (97)	1 (ref.) 0.89 (0.36-2.18)	173 (93)	7,099 (97)	1 (ref.) <b>2.42</b> <b>(1.38-4.24)</b>
Multiple birth	0 (0.0)	58 (2.8)	0 (-)	2 (1.4)	97 (3.4)		5 (2.9)	222 (3.3)		14 (7.5)	253 (3.4)	
<b>Status at birth</b>												
Live births	42 (100)	2,046 (99.8)	1 (ref.)	144 (100)	5,989 (99.8)	1 (ref.)	173 (100)	6,730 (99.7)	1 (ref.)	184 (98.4)	7,318 (99.54)	1 (ref.) <b>4.69</b> <b>(1.40-15.6)</b>
Stillbirths	0 (0.0)	5 (0.2)	0 (-)	0(0.0)	10 (0.2)	0 (-)	0 (0.0)	23 (0.34)	0 (-)	3 (1.6)	26 (0.35)	
<b>Singleton live births</b>	42 (100)	1,983 (100)	<b>OR** (95%CI)</b>	142 (100)	5,788 (100)	<b>OR** (95%CI)</b>	168 (100)	6,435 (100)	<b>OR** (95%CI)</b>	172 (100)	7,075 (100)	<b>OR** (95%CI)</b>
<b>Preterm (&lt;37 weeks)</b>	36 (7.14)	94 (4.81)	1.46 (0.44-4.83)	11(7.75)	295 (5.16)	1.52 (0.81-2.85)	11 (6.55)	352 (5.47)	1.21 (0.65-2.26)	11 (6.43)	343 (4.88)	1.35 (0.73-2.51)
<b>Very preterm (&lt;32 weeks)</b>	2 (4,76)	18 (0,92)	3,99 (0.90-17.66)	3 (2,11)	43 (0,75)	2,88 (0,88-9,39)	0	42 (0,65)	-	3 (1,75)	39 (0,55)	<b>3,41 (1,04-11,16)</b>
<b>Low birth weight (&lt;2500g)</b>	2 (4.76)	116 (5.85)	0.83 (0.20-3.48)	12 (8.45)	327 (5.65)	1.57 (0.86-2.88)	11 (6.55)	353 (5.42)	1.22 (0.66-2.27)	12 (6.98)	341 (4.82)	1.52 (0.83-2.76)

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<b>Very low birth weight (&lt;1500g)</b>	2 (4.76)	20 (1.01)	<b>4.64</b> <b>(1.04-20.6)</b>	3 (2.11)	34 (0.59)	<b>3.66</b> <b>(1.11-12.1)</b>	0 (0.0)	37 (0.57)	0 (-)	2 (1.16)	39 (0.55)	2.18 (0.52-9.12)
<b>Small for gestational age</b>	0 (0.0)	61 (3.1)	0 (-)	4 (2.82)	167 (2.92)	1.00 (0.36-2.74)	5 (2.98)	173 (2.69)	1.11 (0.45-2.75)	6 (3.51)	175 (2.49)	1.45 (0.63-3.31)
*Number and percentage of non-missing values **OR adjusted for maternal age and infant gender (OR contrasting male and female gender adjusted for maternal age, only)												

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**Table 3.** Outcomes of 4,653 births from pregnancies to mothers residing in the Palermo metropolitan area and of 3,980 births from pregnancies to Sicilian women residing in the remaining metropolitan areas (comparison group), conceived between 36 weeks before and 4 weeks after July 29, 2012.

Birth outcome	Palermo exposed Metropolitan Area	Remaining Metropolitan Areas (Catania and Messina)	Unadjusted OR		Adjusted OR	
	N (%)	N (%)				
<b>All Births</b>	4,653 (100)	3,980 (100)	<b>OR</b>	<b>(95%CI)</b>	<b>OR*</b>	<b>(95%CI)</b>
<b>Gender</b>						
Male	2,350 (50.51)	2,040 (51.26)	1 (ref.)		1 (ref.)	
Female	2,303 (49.49)	1,940 (48.74)	1.03	(0.94 – 1.12)	1.03	(0.94 – 1.12)
<b>Plurality</b>						
Singleton birth	4,492 (96.54)	3,829 (96.21)	1 (ref.)		1 (ref.)	
Multiple birth	161 (3.46)	151 (3.79)	0.91	(0.72 - 1.14)	0.91	(0.72 - 1.14)
<b>Status at birth</b>						
<b>Live births</b>	4,636 (99.63)	3,966 (99.65)	1 (ref.)		1 (ref.)	
<b>Stillbirths</b>	17 (0.37)	14 (0.35)	1.04	(0.51 - 2.11)	1.03	(0.51 - 2.10)
<b>Singleton live births</b>	4,492 (100)	3,829 (100)	<b>OR</b>	<b>(95%CI)</b>	<b>OR*</b>	<b>(95%CI)</b>
<b>Preterm</b> (<37 weeks)	169 (7.25)	111 (6.75)	1.08	(0.84 - 1.38)	1.08	(0.84 - 1.39)
<b>Low birth weight</b> (<2.500 gr)	146 (6.74)	180 (7.15)	0.86	(0.69 - 1.08)	0.86	(0.69 - 1.08)
<b>Very low birth weight</b> (<1500 gr)	25 (1.07)	21 (0.83)	1.28	(0.72 - 2.30)	1.28	(0.72 - 2.30)
<b>Small for gestational age</b>	59 (2.53)	66 (4.01)	0.62	(0.43 - 0.89)	0.62	(0.64 – 1.77)

\*OR adjusted for maternal age and infant gender (OR contrasting male and female gender adjusted for maternal age, only)

**Table 4.** Outcome of 536 births from pregnancies to mothers residing in the exposed extra-urban area and of 23,373 births from pregnancies to Sicilian women residing in low inhabitants density and unindustrialized areas of Sicily (comparison group), conceived between 36 weeks before and 4 weeks after July 29, 2011 (the same calendar period during the previous year).

Birth outcome	Extra-urban exposed area	Comparison group	Unadjusted OR		Adjusted OR	
	N (%)	N (%)	OR	(95%CI)	OR*	(95%CI)
<b>All Births</b>	536 (100)	23,373 (100)	<b>OR</b>	<b>(95%CI)</b>	<b>OR*</b>	<b>(95%CI)</b>
<b>Gender</b>						
Male	272 (50.75)	12,041 (51.52)	1 (ref.)		1 (ref.)	
Female	264 (49.25)	11,329 (48.57)	1.03	(0.87 - 1.22)	1.03	(0.87 - 1.22)
<b>Plurality</b>						
Singleton birth	520 (97.01)	22,632 (96.83)	1 (ref.)		1 (ref.)	
Multiple birth	16 (2.99)	741 (3.17)	0.94	(0.57 - 1.56)	0.96	(0.58 - 1.58)
<b>Status at birth</b>						
<b>Live births</b>	534 (99.63)	23,291 (99.65)	1 (ref.)		1 (ref.)	
<b>Stillbirths</b>	2 (0.37)	79 (0.34)	1.10	(0.27 - 4.50)	1.10	(0.27 - 4.50)
<b>Singleton live births</b>			<b>OR</b>	<b>(95%CI)</b>	<b>OR*</b>	<b>(95%CI)</b>
<b>Preterm</b> ( $<37$ weeks)	30 (5.78)	1,226 (5.44)	1.06	(0.731 - 1.54)	1.07	(0.74 - 1.55)
<b>Low birth weight</b> ( $<2.500$ gr)	35 (6.74)	1,226 (5.44)	1.26	(0.88 - 1.78)	1.26	(0.89 - 1.79)
<b>Very low birth weight</b> ( $<1500$ gr)	4 (0.77)	133 (0.59)	1.31	(0.48 - 3.55)	1.31	(0.48 - 3.56)
<b>Small for gestational age</b>	15 (2.89)	616 (2.75)	1.05	(0.62 - 1.77)	1.05	(0.63 - 1.77)

\*OR adjusted for maternal age and infant gender (OR contrasting male and female gender adjusted for maternal age, only)

## Discussion

This retrospective study investigated birth outcomes among women residing near one of the largest Italian solid waste landfills (the Bellolampo MSW-L), who were pregnant during a fire that started on July 29, 2012 and lasted for about a two-week period before being completely extinguished.

As compared to births occurring during the same interval to mothers residing in other areas of Sicily

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3 249 with similar population density and level of industrialization, we observed statistically significant  
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5 250 differences suggesting that the landfill arson could have had an adverse impact on pregnancy  
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8 251 outcomes. Our secondary analysis did not highlight statistically significant differences between the  
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10 252 metropolitan exposed area and the other metropolitan populations in Sicily. In the study group, the  
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12 253 analysis documented a three-fold excess risk of very preterm birth (<32weeks, OR adjusted for  
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14 254 maternal age and infant gender= 3.41; 95%CI= 1.04 - 11.16) and a two-fold excess risk of very low  
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17 255 birth weight (<1500g) among singleton live births. The effect on very low birth weight appeared to  
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19 256 be concentrated among births whose conception date was between 12 weeks prior to the beginning  
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21 257 of the fire to 4 weeks after, suggesting that the largest impact of the exposure may have been on  
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24 258 pregnancies that were conceived during the fire (OR adjusted for maternal age and infant gender=  
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26 259 4.64; 95%CI= 1.04 – 20.6) or were exposed to the fire during the first trimester (OR adjusted for  
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28 260 maternal age and infant gender = 3.66; 95%CI= 1.11 – 12.1). On the other hand, the effect on the  
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31 261 risk of very pre-term birth did not appear to be confined to any particular subgroup at risk. These  
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33 262 findings are compatible with a toxic effect on placentation or early embryo development leading to  
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35 263 restricted intrauterine growth and premature delivery.[18,19] Maternal exposure to ambient  
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38 264 concentrations of air pollutants, particularly to fine particulate matter, has been identified as a risk  
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40 265 factor for preterm birth, low birth weight and SGA births.[20] Multiple studies have documented an  
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42 266 association between fine particulate exposure and preterm birth.[21-23] Exposure to wildfires has  
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45 267 been proposed as a risk factor for preterm birth [20] and reduced average birth weight.[24, 25]  
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47 268 In a multi-site Italian study, maternal exposure to incinerator emissions was associated with preterm  
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49 269 delivery even at very low levels.[7] Moreover, a study conducted in Taiwan concluded that  
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51 270 exposure to emissions from an incinerator generating dioxin had little effects on birth weight and  
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54 271 female birth, but may have a modest effect on gestational age.[8]  
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57 272 The mechanisms proposed to explain the effect of fine particulate exposure on preterm birth include  
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59 273 oxidative stress, pulmonary and placental inflammation, coagulopathy, endothelial dysfunction and  
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274 hemodynamic responses,[20, 26] as well as intrauterine inflammation.[20] Of interest, adverse

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3 275 pregnancy outcomes including pre-term delivery, intrauterine growth restriction and impaired infant  
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5 276 weight gain are associated with exposure to polychlorinated dibenzo-*p*-dioxins (PCDDs),  
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8 277 polychlorinated dibenzofurans (PCDFs) and dioxin-like PCBs (DL-PCBs).[1] Recently, The  
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10 278 Hokkaido Study on Environment and Children's Health has demonstrated the effects of  
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12 279 environmental chemical exposures (dioxins, polychlorinated biphenyls, organochlorine pesticides,  
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15 280 perfluoroalkyl substances, phthalates, bisphenol A, and methylmercury) on genetically susceptible  
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17 281 populations and on DNA methylation,[27, 28] while other research suggests that exposure to  
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19 282 tetrachlorodibenzo-*p*-dioxin (TCDD) may induce shifts in the immune response that enhance a  
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22 283 proinflammatory phenotype at the maternal-fetal interface, increasing the risk of infection-mediated  
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24 284 preterm birth.[29]

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26 285 The body of published evidence, taken together with the statistically significant excess risk  
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29 286 concentrated in a relatively narrow period of susceptibility, lends credibility to the hypothesis that  
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31 287 the Bellolampo arson adversely affected pregnancies exposed during conception or in the first  
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33 288 trimester, causing an excess of deliveries of very low birth weight infants in the extra-urban area.

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35 289 The study also documented in the same area a significant four-fold excess of stillbirths among  
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38 290 pregnancies that were exposed to the landfill fire during the third trimester. This finding is based on  
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40 291 a total of three stillbirths that occurred in the extra-urban study group, all of which were  
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42 292 concentrated to the subgroup exposed during the third trimester, and it is possible that the observed  
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45 293 excess is due to chance even if it was statistically significant. On the other hand, long-term  
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47 294 exposure to PCBs was associated with increased proportions of miscarriage and stillbirth in animal  
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49 295 studies,[30] and exposure to emissions from solid-waste incinerators was associated with increased  
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52 296 risk of miscarriage in an epidemiologic study in Italy.[31] Thus, the excess of stillbirths to mothers  
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54 297 exposed during the third trimester could be associated with the arson.

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56 298 The excess of multiple births from pregnancies exposed during the third trimester in the study group  
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59 299 is unlikely to be caused by exposure to the landfill fire, as plurality must have been established long  
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3 300 before the arson. The literature provides conflicting evidence on the association between exposure  
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5 301 to air pollution from incinerators and multiple births.[32]  
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8 302 Long-term exposure of the study area to pollutants (independently from the fire) was already known  
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10 303 and was confirmed by the detection of TCCD and heavy metals at concentrations above the limits  
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12 304 permitted by law [33] in sub-soil samples collected by the regional environment protection agency  
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15 305 after the fire.[34] However, the secondary analysis comparing birth outcomes in the same extra-  
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17 306 urban groups in the year before the arson did not highlight any potential effect related to a long-  
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19 307 term exposure to pollutants emitted from the landfill.  
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21 308 The findings of this study should be interpreted in light of some limitations. First, the retrospective  
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24 309 design and the analysis of data from vital statistics do not allow a detailed assessment of the  
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26 310 longitudinal nature of the exposure-response relation, or precise adjustment for potential  
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28 311 confounding. Although environmental monitoring was performed in response to the arson, we had  
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31 312 limited access to the data and could only confirm the increase in air particulate concentrations after  
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33 313 the beginning of the fire. Thus, we could not assess specific exposure levels of individual  
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35 314 pregnancies at multiple points in time. Lastly, as it is often the case in studies of local  
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38 315 environmental exposure events, the outcomes of interest were limited in number, especially when  
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40 316 stratified according to the stage of the pregnancy at exposure. Nevertheless, the observations made  
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42 317 in this study are of general interest. While previous studies conducted in Italy have suggested  
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44 318 associations between exposure to incinerator emissions and increased risk of miscarriages and  
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47 319 preterm births,[31] to our knowledge, the present study is the first in Europe to investigate the  
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49 320 effects of exposure emissions on birth outcomes evaluating pregnancies exposed at different stages  
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51 321 of development. Despite the limited information base and sample size, the excess of very low birth  
52  
53 322 weight infants achieved statistical significance and was confined to early-stage pregnancies.  
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56 323 The study adds to the growing body of evidence that exposure to emissions from solid waste  
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58 324 landfill operations may have serious health effects and underscores the need for monitoring  
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60 325 potential hazards and health outcomes in the resident population.[35] The arsons at the Bellolampo

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326 MSW-L,[36] as well as the ones that occurred in other Italian solid waste treatment plants in  
327 proximity to populated areas,[10] and the public concern they caused, exemplify the important role  
328 that integration of environmental monitoring and epidemiologic surveillance may have in this  
329 realm.[37-39] The questionable strength of the evidence collected in this and in similar studies also  
330 underscores the need for better planning of monitoring and surveillance activities (more detailed  
331 exposure information, better definition and monitoring of reproductive and other health outcomes,  
332 assessment of long-term effects and better control for potential confounders), and highlights the  
333 difficulty of conveying results to the various stakeholders [9] and the related need for effective  
334 methods to transfer study results to policy makers and the public.[40]  
335 Finally, our study highlights the importance to promote an integrated management of urban solid  
336 waste alternatives to landfills, including waste to energy plants or other newly available  
337 technologies such as pyrolysis and gasification.[41]

### **Ethics**

339 Ethical approval was obtained by the “Palermo Ethical Committee 1” on February 14, 2018  
340 (protocol number: 02/2018).

### **Data sharing**

342 No additional data available.

### **Funding**

344 No funding received.

### **Competing interests**

346 The authors declare they have no actual or potential competing interests.

### **Authors’ contributions**

348 All individuals listed as authors have contributed substantially to designing, performing or reporting  
349 the study and every specific contribution is indicated as follows. Conception and design of the  
350 study: WM, MM, RC, AC. Data collection: ET, AC, SS. Statistical analysis: ET, AC, RG, MM,  
351 WM. Interpretation of data: CC, CM, WM, MM, AC, ET. Manuscript writing and drafting: WM,

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352 MM, CM, AC, DA. Revision of the manuscript: WM, CM, MM, SS, FV. Approval of the final  
353 version of the manuscript: WM, ET, MM, CM, RC, DA, CC, RG, AC, SS, FV.

### 354 **Acknowledgments**

355 The authors are grateful to the Regional Environmental Protection Agency of Sicily (ARPA Sicilia)  
356 for technical assistance with the study design.

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471 **Figure 1.** Bellolampo solid waste landfill arson: pregnancy stage at exposure among resident  
472 mothers and key statistically significant findings documented for the extra-urban area (the arrows  
473 represent the health outcomes associated to the exposure to the pollutants emitted by the arson).

474  
475 **Supplementary File.** Under surveillance area exposed to emissions deriving from the Bellolampo  
476 municipal solid waste landfill (Borgetto, Capaci, Carini, Giardinello, Montelepre, Torretta):  
477 Metropolitan area (Palermo) and extra-urban area (in red).

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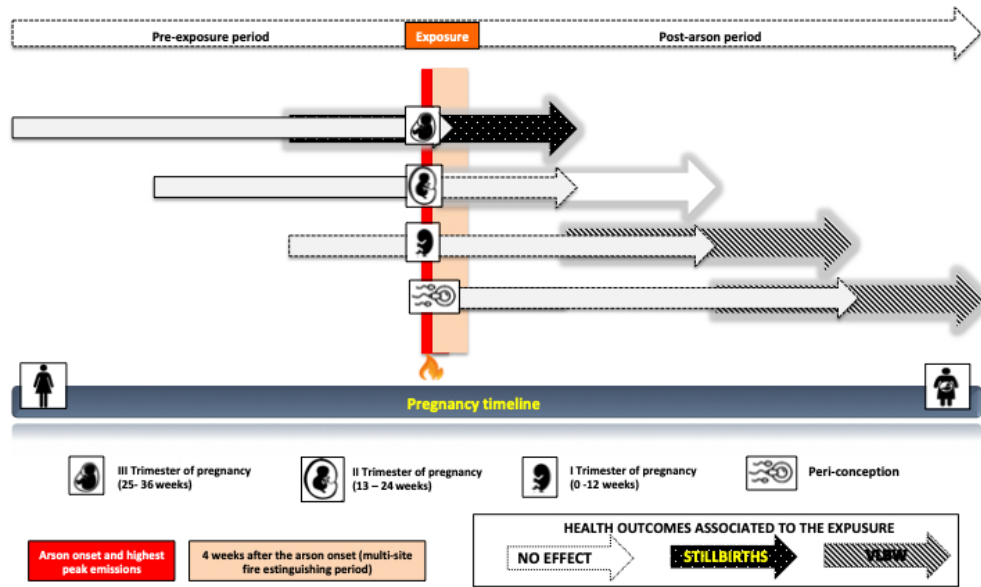
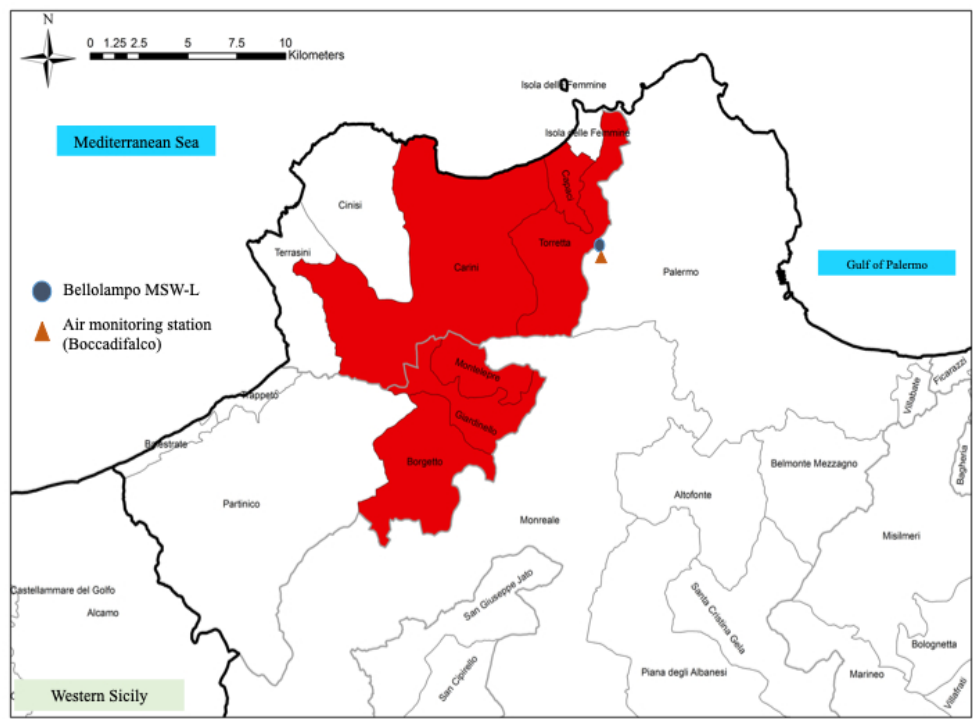


Figure 1. Bellolampo solid waste landfill arson: pregnancy stage at exposure among resident mothers and key statistically significant findings documented for the extra-urban area (the arrows represent the health outcomes associated to the exposure to the pollutants emitted by the arson).

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## STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4 - 6
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	4-6
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6
Bias	9	Describe any efforts to address potential sources of bias	5
Study size	10	Explain how the study size was arrived at	4
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5-6
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	5-6
		(b) Describe any methods used to examine subgroups and interactions	5-6
	(c) Explain how missing data were addressed	NA	
	(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	NA	
	(e) Describe any sensitivity analyses	NA	

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<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6-7
		(b) Give reasons for non-participation at each stage	NA
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6
		(b) Indicate number of participants with missing data for each variable of interest	NA
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	7-9
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	NA
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	NA
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	7-9
		(b) Report category boundaries when continuous variables were categorized	9-11
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	11-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13
Generalisability	21	Discuss the generalisability (external validity) of the study results	15
<b>Other information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15

\*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).

# BMJ Open

## Do emissions from landfill fires affect pregnancy outcomes? A retrospective study after arson at a solid waste facility in Sicily.

Journal:	<i>BMJ Open</i>
Manuscript ID	bmjopen-2018-027912.R2
Article Type:	Research
Date Submitted by the Author:	19-Jun-2019
Complete List of Authors:	<p>MAZZUCCO, WALTER; University of Palermo, Health Promotion Sciences, Maternal and Infant Care, Internal Medicine and Medical Specialties (PROMISE) Department, University of Palermo, Palermo, Italy; Palermo University Hospital "P. Giaccone", Clinical Epidemiology and Cancer Registry Unit, Palermo University Hospital "P. Giaccone", Palermo, Italy</p> <p>Tavormina, Elisa; Regional Health Authority, Department of Health Services and Epidemiological Observatory</p> <p>Macaluso, M; Cincinnati Children's Hospital Medical Center, Division of Biostatistics and Epidemiology; University of Cincinnati College of Medicine, Department of Pediatrics</p> <p>Marotta, Claudia; University of Palermo, Health Promotion Sciences, Maternal and Infant Care, Internal Medicine and Medical Specialties (PROMISE) Department, University of Palermo, Palermo, Italy</p> <p>Cusimano, Rosanna; Palermo University Hospital "P. Giaccone", Clinical Epidemiology and Cancer Registry Unit, Palermo University Hospital "P. Giaccone", Palermo, Italy</p> <p>Alba, Davide; University of Palermo, Sciences for health promotion (PROSAMI) Department</p> <p>Costantino, Claudio; University of Palermo, Sciences for health promotion (PROSAMI) Department</p> <p>Grammauta, Rosario; National Research Council, Institute for the Study of Anthropogenic Impacts and Sustainability in the Marine Environment (IAS), National Research Council</p> <p>Cernigliaro, Achille; Regional Health Authority, Department of Health Services and Epidemiological Observatory</p> <p>Scondotto, Salvatore; Regional Health Authority, Department of Health Services and Epidemiological Observatory</p> <p>Vitale, Francesco; University of Palermo, Health Promotion Sciences, Maternal and Infant Care, Internal Medicine and Medical Specialties (PROMISE) Department, University of Palermo; Palermo University Hospital "P. Giaccone", Clinical Epidemiology and Cancer Registry Unit, Palermo University Hospital "P. Giaccone"</p>
<b>Primary Subject Heading</b>:	Epidemiology
Secondary Subject Heading:	Reproductive medicine
Keywords:	PUBLIC HEALTH, Maternal medicine < OBSTETRICS, Enviromental health, exposure to air pollutant

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3 1 **Title page**  
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5 2 **Title:** Do emissions from landfill fires affect pregnancy outcomes? A retrospective study after arson  
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8 3 at a solid waste facility in Sicily.  
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10 4  
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12 5 **Authors**  
13

14 6 Walter Mazzucco\* <sup>a,b</sup>, Elisa Tavormina <sup>c</sup>, Maurizio Macaluso\* <sup>d</sup>, Claudia Marotta <sup>a</sup>, Rosanna  
15  
16  
17 7 Cusimano <sup>f</sup>, Davide Alba <sup>a</sup>, Claudio Costantino <sup>a</sup>, Rosario Grammata <sup>g</sup>, Achille Cernigliaro <sup>c</sup>,  
18  
19 8 Salvatore Scondotto <sup>c</sup>, Francesco Vitale <sup>a,b</sup>.

20  
21 9 \*These authors contributed equally.  
22  
23

24 10  
25  
26 11 <sup>a</sup> Health Promotion Sciences, Maternal and Infant Care, Internal Medicine and Medical Specialties  
27  
28 12 (PROMISE) Department, University of Palermo, Palermo, Italy

29 13  
30 13 <sup>b</sup> Clinical Epidemiology and Cancer Registry Unit, Palermo University Hospital "P. Giaccone",  
31  
32 14 Palermo, Italy

33 15  
34 15 <sup>c</sup> Department of Health Services and Epidemiological Observatory, Regional Health Authority,  
35  
36 16 Sicilian Region, Palermo, Italy

37 17  
38 17 <sup>d</sup> Division of Biostatistics and Epidemiology, Cincinnati Children's Hospital Medical Center, and  
39  
40 18 Department of Pediatrics, University of Cincinnati College of Medicine, Cincinnati, OH, USA

41  
42 19  
43 19 <sup>f</sup> Palermo Health Agency, Palermo, Italy

44 20  
45 20 <sup>g</sup> Institute for the Study of Anthropogenic Impacts and Sustainability in the Marine Environment  
46  
47 21 (IAS), National Research Council, Torretta Granitola (Trapani), Italy  
48  
49 22

50  
51 23 Corresponding author:  
52

53 24 Claudia Marotta, Dipartimento Scienze Promozione della Salute e Materno Infantile "G.  
54  
55 25 D'Alessandro", Università degli Studi di Palermo. Via del Vespro, 133 - 90127 Palermo, Italy  
56  
57 26

58  
59  
60 Telephone number: +393337984116 Fax: +390916553631

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3 27 E-mail: marotta.claudia@gmail.com  
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5 28 **Word count:** 4.156  
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10 30 **Abstract**  
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12 31 **Objectives:** In response to public health concern about effects of arson at solid waste management  
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14 32 plants in July 2012, we analysed vital statistics data to evaluate any potential effect on pregnancies  
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17 33 at different gestational ages of pollutants emitted from the landfill on fire.  
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19 34 **Setting:** A community living near the largest landfill plant in Sicily.  
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21 36 **Participants:** The study group comprised 551 births live births and stillbirths from pregnancies of  
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24 37 mothers residing in the extra-urban exposed area, conceived during a 40-week period during which  
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26 38 the highest fire's peak might have influenced pregnancy.  
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28 39 **Primary and secondary outcome measures:** Birth outcomes (gestational age <37 and <32 weeks,  
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31 40 low birth weight, very low birth weight and small for gestational age) in the study group were  
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33 41 compared to the ones of a reference group of women residing in areas of Sicily with similarly low  
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35 42 population density and industrial development.  
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37 43 **Results:** Among singleton live births we observed a three-fold increase in risk of very preterm birth  
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40 44 between the extra-urban area and the remaining low inhabitants density and unindustrialized areas  
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42 45 for births whose pregnancies were in the third trimester (OR adjusted for maternal age and infant  
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44 46 gender= 3.41; 95%CI= 1.04 - 11.16). There was an excess of very low birth weight singleton  
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47 47 infants in the study group as compared to the reference group, which was limited to births to  
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49 48 mothers exposed during peri-conception period (OR adjusted for maternal age and infant gender=  
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51 49 4.64; 95%CI= 1.04 – 20.6) and first trimester (OR adjusted for maternal age and infant gender =  
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53 50 3.66; 95%CI= 1.11 – 12.1). The association estimates were imprecise due to the small number of  
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56 51 outcomes recorded.  
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58 52 **Conclusions:** The study documented an excess of very preterm and very low birth weight among  
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60 53 infants born to mothers exposed to the landfill fire emissions during conception or early pregnancy.

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56 55 **Strengths and limitations of this study**  
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- 8 56 • Arson at an urban solid waste facility allowed us to investigate the potential reproductive  
9 health effects of short-term exposure to pollutants emitted from the combustion of solid  
10 57 waste.  
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15 59 • The analysis of vital records data allowed us to assess birth outcomes of pregnancies  
16 exposed at distinct stages of development, from conception to the time of delivery.  
17 60  
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20 61 • Data obtained from the regional Certificate of Birth Attendance registry allowed comparing  
21 exposed and non-exposed groups employing standardized information on birth outcomes.  
22 62  
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25 63 • The retrospective design and the limited vital statistics data available for analysis did not  
26 allow a detailed assessment of the longitudinal nature of the exposure-response relation, or a  
27 64 precise adjustment for potential confounding.  
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30 65  
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32 66 • As it is often the case in studies of local environmental exposure events, the number of  
33 relevant outcomes was limited, especially when stratified according to the stage of the  
34 67 pregnancy at exposure, and association estimates were imprecise.  
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41 70 **Key words:** exposure to air pollutant; landfill emissions; low birth-weight; conception; early  
42 pregnancy.  
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48 73 **Introduction**  
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50 74 The number of studies investigating the potential human health effects on communities of pollutants  
51 released from landfills or incinerators is increasing,[1,2] showing that exposure is weakly associated  
52 75 with a variety of adverse health outcomes, including cancer, adverse reproductive outcomes and  
53 76 birth defects.[3-5] Increased risk of low birth weight and congenital malformations has been  
54 77 reported in communities living in proximity to landfills.[2,6] Maternal exposure to incinerator  
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3 79 emissions was associated with preterm delivery.[7] A study of exposure to incinerator emissions  
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5 80 containing dioxin concluded that exposure had little impact on birth weight and sex ratio, but may  
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8 81 have been associated with gestational age at delivery.[8] Inconsistent findings across studies may  
9  
10 82 be due to design issues, lack of exposure information, use of indirect surrogate measures, acute  
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12 83 versus long-term exposure conditions, and inadequate control of confounding.[9] Variation in risk  
13  
14 84 perception among the stakeholders makes it difficult to communicate about the available evidence.  
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17 85 In Italy, the incidence of fires in solid waste management plants is increasing.[10] addressing the  
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19 86 need to investigate the potential health effects of short-term exposure to pollutants emitted from the  
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21 87 combustion of solid waste.  
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24 88 In Sicily, the fourth most populated Italian region, 5 million residents produce about 6,000 tons of  
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26 89 solid waste daily, which are disposed of in 4 Municipal Solid Waste Landfills (MSW-L).[11] The  
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28 90 largest MSW-L is located in Bellolampo at 450 meters above sea level, on the hidden side of a  
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30 91 mountain at the south-western border of Palermo (the largest city in Sicily, with 700,000  
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32 92 inhabitants, and its administrative capital).[11] The Bellolampo MSW-L collects solid waste from  
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34 93 the Palermo metropolitan area, which includes the city and nearby municipalities.[12] On July 29,  
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36 94 2012, a fire started at multiple points within the landfill and emissions spread to a large populated  
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38 95 area, causing concern for the public's health. Emissions peaked in the first 24 hours and decreased  
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40 96 thereafter, until the fire was fully extinguished by August 16, 2012.  
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44 97 We analyzed vital statistics data to retrospectively evaluate the potential effects of the arson on the  
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46 98 outcomes of pregnancies that were exposed to the emissions at different gestational ages.  
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## 51 100 **Methods**

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53 101 In response to the arson, the Sicilian Regional Health Authority defined an administrative area  
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55 102 around the landfill, whose resident population was considered as potentially exposed to the MSW-L  
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57 103 emissions and placed under surveillance (**Supplementary file**).[13] Environmental monitoring of  
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59 104 the area [14] was done through existing stationary monitoring stations.[15] A longitudinal



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3 105 retrospective study was designed to study the effects of exposure to the fire emissions on  
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5 106 reproductive health outcomes. We obtained limited data from the regional Certificate of Birth  
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8 107 Attendance (CedAP) registry, which collects information on all births to women of childbearing age  
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10 108 (10-55 years old) who deliver in Sicily, including parental socio-demographic characteristics,  
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12 109 obstetric history, prenatal care, and characteristics of pregnancy and birth. The CedAP registry does  
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15 110 not include data on births to resident mothers who delivered outside the region or wanted to  
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17 111 preserve anonymity (0.4%). Date of conception was estimated using the date of birth and  
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19 112 gestational age at birth reported in the registry. The study included all live births and stillbirths to  
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22 113 mothers residing within the surveillance zone, whose estimated conception date occurred from 36  
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24 114 weeks prior to the peak of the fire (from 2:00PM on July 29, 2012 to 2:00PM on July 30, 2012),  
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26 115 until 4 weeks after the fire. To remove confounding by exposure to pollutants deriving from  
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28 116 anthropic activities and vehicular traffic within metropolitan areas, we restricted the main focus of  
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31 117 the analysis to residents of the extra-urban section of the surveillance area (**Supplementary file**).  
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33 118 Thus, the study group included all live births and stillbirths in the extra-urban surveillance area  
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35 119 from pregnancies that were potentially exposed to the fire around the time of conception as well as  
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38 120 pregnancies that were exposed at later stages (through the 36<sup>th</sup> week). The reference group  
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40 121 comprised all live births and stillbirths to mothers residing in the remaining extra-urban, low-  
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42 122 density and unindustrialized areas of Sicily, during the same time interval. To distinguish pregnancy  
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45 123 periods of susceptibility to acute exposure to the fire emissions, we stratified the study group and  
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47 124 the reference population according to the following four sub-periods of exposure (**Figure 1**):  
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49 125 i) peri-conception (conception occurring on July 29, 2012 or up to 4 weeks later);  
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51 126 ii) first trimester (conception date 12-0 weeks before July 29, 2012);  
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54 127 iii) second trimester (24-13 weeks before July 29, 2012);  
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56 128 iv) third trimester (36-25 weeks before July 29, 2012).  
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3 129 For each stage of the pregnancy at the time of exposure, we compared birth outcomes of the study  
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5 130 group with those of the reference group. We also carried out internal comparisons within the study  
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8 131 group, contrasting outcomes across the four sub-periods of exposure.  
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10 132 We conducted two supplementary analyses: first, we compared birth outcomes to mothers in the  
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12 133 metropolitan area of Palermo (the main metropolitan area served by the Bellolampo MSW-L,  
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14 134 656,829 inhabitants) with those to mothers residing in the two other Sicilian metropolitan areas  
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17 135 (Catania, 293,104 inhabitants, and Messina, 242,914 inhabitants) in the same study period. Second,  
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19 136 to assess any systematic difference between the study group and the reference group independently  
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22 137 from the fire, we repeated the comparison using data on births that occurred during the year  
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24 138 preceding the arson (specifically, births conceived within -36 and +4 weeks from July 29, 2011).  
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26 139 For each comparison, we evaluated the following proportions, defined according to European  
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28 140 guidelines for perinatal statistics adopted by the PERISTAT system[16,17]: a) among all births (i.e.,  
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30 141 live births and stillbirths combined): proportion of stillbirths, proportions of male and female births,  
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33 142 and proportions of singleton and multiple births; b) among live births: preterm birth (gestational age  
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35 143 <37 weeks), very preterm birth (gestational age <32 weeks), low birth weight (<2,500 grams), very  
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38 144 low birth weight (<1,500 grams) and small for gestational age (SGA) (birth weight under the tenth  
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40 145 percentile of the national distribution of birth weights of the same gestational age or birth of  
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42 146 gestational age  $\geq 37$  weeks weighing <2,500 grams).  
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44 147 Because of CedAP data flow at the time in study was relatively new, we were only able to use the  
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47 148 limited information described in this manuscript.  
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49 149 To make statistical inference about the comparisons between the different study groups and the  
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51 150 references, we used logistic regression to estimate odds ratios (OR) and 95% confidence intervals  
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54 151 (CI) of the ORs, with and without adjusting for maternal age and infant gender, the only two  
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56 152 potential confounders made available to us. Throughout this paper we treated the OR as an estimate  
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58 153 of the risk ratio. This is appropriate as the absolute risks for most of the outcomes considered are  
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60 154 well below 10%, and under these conditions the OR closely approximates the RR. Statistical

155 analyses were carried out using STATA (version 11.2 MP, StataCorp, College Station, TX).

156 STROBE guidelines were followed for research reporting.

### 157 Patient and Public Involvement

158 Patients were not involved.

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### 160 Results

161 Mothers residing in the exposed extra-urban area (the study group) gave birth to a total of 551  
 162 infants (548 live born + 3 stillborn) conceived during the interval of interest (11/20/2011-  
 163 08/26/2012). There were 22,341 births (22,264 live births + 65 stillbirths) from pregnancies  
 164 conceived during the same period by mothers residing in the remaining Sicilian low population-  
 165 density, low industrialization areas (the comparison group). We observed a two-fold increase in risk  
 166 of very preterm birth (OR adjusted for maternal age and infant gender= 2.29; 95%CI= 1.12 - 4.68)  
 167 and a two-fold increase in risk of very low birth weight (OR adjusted for maternal age and infant  
 168 gender= 2.20; 95%CI= 1.02 - 4.72) among singleton live births (**Table 1**).

169 **Table 1.** Outcomes of 551 births from pregnancies to mothers residing in the extra-urban area  
 170 (study group) and of 22,342 births from pregnancies to Sicilian women residing in similar low  
 171 population density, low industrialization areas (comparison group), conceived between 36 weeks  
 172 before and 4 weeks after July 29, 2012.

Birth outcome	Extra-urban exposed area	Comparison group	Unadjusted OR		Adjusted OR	
	N (%)	N (%)	OR	(95%CI)	OR**	(95%CI)
<b>All Births</b>	551 (100)	22,342 (100)				
<b>Gender</b>		7 (0,03)*				
Male	299 (54.26)	11,464 (51.31)	1 (ref.)		1 (ref.)	
Female	252 (45.74)	10,871 (48.66)	0.89	(0.75 - 1.05)	0.8	(0.75 - 1.05)
<b>Plurality</b>						
Singleton birth	530 (96.19)	21,594 (96.65)	1 (ref.)		1 (ref.)	
Multiple birth	21 (3.81)	748 (3.35)	1.14	(0.73 - 1.78)	1.17	(0.75 - 1.82)
<b>Status at birth</b>		13 (0,06)*				
<b>Live births</b>	548 (99.46)	22,264 (99.65)	1 (ref.)		1 (ref.)	
<b>Stillbirths</b>	3 (0.54)	65 (0.29)	1.88	(0.59 - 5.98)	1.89	(0.59 - 6.03)
<b>Singleton live births</b>	530 (100)	21,525 (100)				
<b>Preterm (&lt;37 weeks)</b>	36 (6.82)	1,094 (5.13)	1.35	(0.96 - 1.91)	1.35	(0.96 - 1.90)

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173	<b>Very preterm</b>							Among all births, we observed
174	(<32 weeks)	8 (1.52)	144 (0.68)	<b>2.26</b>	<b>(1.10 – 4.63)</b>	<b>2.29</b>	<b>(1.12 – 4.68)</b>	
175	<b>Low birth weight</b>							
176	(<2.500 gr)	37 (6.99)	1,143 (5.31)	1.34	(0.95 - 1.88)	1.36	(0.97 - 1.91)	
177	<b>Very low birth weight</b>							
178	(<1500 gr)	7 (1.32)	131 (0.61)	<b>2.19</b>	<b>(1.02 - 4.71)</b>	<b>2.20</b>	<b>(1.02- 4.72)</b>	
179	<b>Small for gestational age</b>	15 (2.84)	578 (2.71)	1.05	(0.62 - 1.76)	1.07	(0.65 – 1.80)	
*Number and percentage of non-missing values **OR adjusted for maternal age and infant gender (OR contrasting male and female gender adjusted for maternal age, only)								

differences between the study group and the comparison group that were limited to births whose pregnancies were in the third trimester when the fire began: a twofold excess of multiple births (OR adjusted by gender= 2.42; 95%CI= 1.38-4.24) and a fourfold excess of stillbirths (OR adjusted by gender= 4.69; 95%CI= 1.40-15.6) (**Table 2**).

Among singleton live births we observed a three-fold increase in risk of very preterm between the extra-urban area and the remaining Sicilian low inhabitants density and unindustrialized areas for births whose pregnancies were in the third trimester (OR adjusted for maternal age and infant gender= 3.41; 95%CI= 1.04 - 11.16) when the fire began (**Table 2**).

Among singleton live births there were differences in very low birth weight rates between the extra-urban area and the remaining Sicilian low inhabitants density and unindustrialized areas for births whose pregnancies were either in peri-conception period (OR adjusted for maternal age and infant gender= 4.64; 95%CI= 1.04 – 20.6) or in the first trimester (OR adjusted for maternal age and infant gender= 3.66; 95%CI= 1.11 – 12.1) when the fire began (**Table 2**). Additional analyses of the risk of very low birth weight stratified by gestational age revealed that the excess of very low birth weight overlapped only in part with very preterm birth: remarkably, the infants accounting for the excess of very low birth weight from pregnancies conceived around the time of exposure were born after 32 weeks of gestation (results not shown in detail). Internal comparisons of the susceptibility period within the extra-urban exposed group did not reveal clear differences between

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198 subgroups defined by stages of the pregnancy at the time of exposure, but these comparisons were  
199 hampered by the small size of the study group (results not shown).

200 Our supplementary analyses did not show differences between the outcomes of 4,653 births to  
201 mothers residing in the Palermo metropolitan area which were conceived between 36 weeks before  
202 and 4 weeks after July 29, 2012 and the outcomes of 3,980 births to mothers residing in the other  
203 Sicilian metropolitan areas conceived during the same time interval (**Table 3**). Similarly, we  
204 observed no differences between the outcomes of births from pregnancies to mothers residing in the  
205 extra-urban exposed area and the outcomes of births from pregnancies to Sicilian women residing in  
206 low population-density, low-industrialization areas of Sicily, conceived between 36 weeks before  
207 and 4 weeks after July 29, 2011 (one year before the arson) (**Table 4**).

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**Table 2.** Outcomes of births from pregnancies to mothers residing in the exposed extra-urban area and of births from pregnancies to Sicilian women residing in similar low population density, low industrialization areas (comparison groups) by susceptibility sub-periods.

Birth outcome	Pregnancy stage as of the beginning of the fire (July 29, 2012)											
	Peri-conception			I Trimester (12-0 weeks)			II Trimester (24-13 weeks)			III Trimester (36-25 weeks)		
	Extra-urban exposed area	Comparison Group	OR** (95%CI)	Extra-urban exposed area	Comparison Group	OR** (95%CI)	Extra-urban exposed area	Comparison Group	OR** (95%CI)	Extra-urban exposed area	Comparison Group	OR** (95%CI)
	N (%)*	N (%)		N (%)	N (%)		N (%)*	N (%)*		N (%)	N (%)	
<b>All Births</b>	42 (100)	2,051 (100)		144 (100)	6,000 (100)		173 (100)	6,757 (100)		187 (100)	7,352 (100)	
<b>Gender</b>												
Male	27 (64)	1,054 (51)	1 (ref.) 0.59 (0.31-1.11)	82 (57)	3,129 (52)	1 (ref.) 0.82 (0.59-1.15)	88 (51)	3,430 (51)	1 (ref.) 0.99 (0.74-1.35)	101 (54)	3,755 (51)	1 (ref.) 0.89 (0.67-1.19)
Female	15 (36)	997 (49)		62 (43)	2,870 (48)		85 (49)	3,327(49)		86 (46)	3,591(49)	
<b>Plurality</b>												
Singleton birth	42 (100)	1993 (97)	1 (ref.)	142 (99)	5,793 (97)	1 (ref.) 0.4 (0.09-1.62)	168 (97)	6,535 (97)	1 (ref.) 0.89 (0.36-2.18)	173 (93)	7,099 (97)	1 (ref.) 2.42 (1.38-4.24)
Multiple birth	0 (0.0)	58 (2.8)	0 (-)	2 (1.4)	97 (3.4)		5 (2.9)	222 (3.3)		14 (7.5)	253 (3.4)	
<b>Status at birth</b>												
Live births	42 (100)	2,046 (99.8)	1 (ref.)	144 (100)	5,989 (99.8)	1 (ref.)	173 (100)	6,730 (99.7)	1 (ref.)	184 (98.4)	7,318 (99.54)	1 (ref.) 4.69 (1.40-15.6)
Stillbirths	0 (0.0)	5 (0.2)	0 (-)	0(0.0)	10 (0.2)	0 (-)	0 (0.0)	23 (0.34)	0 (-)	3 (1.6)	26 (0.35)	
<b>Singleton live births</b>	42 (100)	1,983 (100)	OR** (95%CI)	142 (100)	5,788 (100)	OR** (95%CI)	168 (100)	6,435 (100)	OR** (95%CI)	172 (100)	7,075 (100)	OR** (95%CI)
<b>Preterm (&lt;37 weeks)</b>	36 (7.14)	94 (4.81)	1.46 (0.44-4.83)	11(7.75)	295 (5.16)	1.52 (0.81-2.85)	11 (6.55)	352 (5.47)	1.21 (0.65-2.26)	11 (6.43)	343 (4.88)	1.35 (0.73-2.51)
<b>Very preterm (&lt;32 weeks)</b>	2 (4,76)	18 (0,92)	3,99 (0.90-17.66)	3 (2,11)	43 (0,75)	2,88 (0,88-9,39)	0	42 (0,65)	-	3 (1,75)	39 (0,55)	3,41 (1,04-11,16)
<b>Low birth weight (&lt;2500g)</b>	2 (4.76)	116 (5.85)	0.83 (0.20-3.48)	12 (8.45)	327 (5.65)	1.57 (0.86-2.88)	11 (6.55)	353 (5.42)	1.22 (0.66-2.27)	12 (6.98)	341 (4.82)	1.52 (0.83-2.76)

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<b>Very low birth weight (&lt;1500g)</b>	2 (4.76)	20 (1.01)	<b>4.64</b> <b>(1.04-20.6)</b>	3 (2.11)	34 (0.59)	<b>3.66</b> <b>(1.11-12.1)</b>	0 (0.0)	37 (0.57)	0 (-)	2 (1.16)	39 (0.55)	2.18 (0.52-9.12)
<b>Small for gestational age</b>	0 (0.0)	61 (3.1)	0 (-)	4 (2.82)	167 (2.92)	1.00 (0.36-2.74)	5 (2.98)	173 (2.69)	1.11 (0.45-2.75)	6 (3.51)	175 (2.49)	1.45 (0.63-3.31)
*Number and percentage of non-missing values **OR adjusted for maternal age and infant gender (OR contrasting male and female gender adjusted for maternal age, only)												

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**Table 3.** Outcomes of 4,653 births from pregnancies to mothers residing in the Palermo metropolitan area and of 3,980 births from pregnancies to Sicilian women residing in the remaining metropolitan areas (comparison group), conceived between 36 weeks before and 4 weeks after July 29, 2012.

Birth outcome	Palermo exposed Metropolitan Area	Remaining Metropolitan Areas (Catania and Messina)	Unadjusted OR		Adjusted OR	
	N (%)	N (%)				
<b>All Births</b>	4,653 (100)	3,980 (100)	<b>OR</b>	<b>(95%CI)</b>	<b>OR*</b>	<b>(95%CI)</b>
<b>Gender</b>						
Male	2,350 (50.51)	2,040 (51.26)	1 (ref.)		1 (ref.)	
Female	2,303 (49.49)	1,940 (48.74)	1.03	(0.94 – 1.12)	1.03	(0.94 – 1.12)
<b>Plurality</b>						
Singleton birth	4,492 (96.54)	3,829 (96.21)	1 (ref.)		1 (ref.)	
Multiple birth	161 (3.46)	151 (3.79)	0.91	(0.72 - 1.14)	0.91	(0.72 - 1.14)
<b>Status at birth</b>						
<b>Live births</b>	4,636 (99.63)	3,966 (99.65)	1 (ref.)		1 (ref.)	
<b>Stillbirths</b>	17 (0.37)	14 (0.35)	1.04	(0.51 - 2.11)	1.03	(0.51 - 2.10)
<b>Singleton live births</b>	4,492 (100)	3,829 (100)	<b>OR</b>	<b>(95%CI)</b>	<b>OR*</b>	<b>(95%CI)</b>
<b>Preterm</b> (<37 weeks)	169 (7.25)	111 (6.75)	1.08	(0.84 - 1.38)	1.08	(0.84 - 1.39)
<b>Low birth weight</b> (<2.500 gr)	146 (6.74)	180 (7.15)	0.86	(0.69 - 1.08)	0.86	(0.69 - 1.08)
<b>Very low birth weight</b> (<1500 gr)	25 (1.07)	21 (0.83)	1.28	(0.72 - 2.30)	1.28	(0.72 - 2.30)
<b>Small for gestational age</b>	59 (2.53)	66 (4.01)	0.62	(0.43 - 0.89)	0.62	(0.64 – 1.77)

\*OR adjusted for maternal age and infant gender (OR contrasting male and female gender adjusted for maternal age, only)



**Table 4.** Outcome of 536 births from pregnancies to mothers residing in the exposed extra-urban area and of 23,373 births from pregnancies to Sicilian women residing in low inhabitants density and unindustrialized areas of Sicily (comparison group), conceived between 36 weeks before and 4 weeks after July 29, 2011 (the same calendar period during the previous year).

Birth outcome	Extra-urban exposed area	Comparison group	Unadjusted OR		Adjusted OR	
	N (%)	N (%)	OR	(95%CI)	OR*	(95%CI)
<b>All Births</b>	536 (100)	23,373 (100)	<b>OR</b>	<b>(95%CI)</b>	<b>OR*</b>	<b>(95%CI)</b>
<b>Gender</b>						
Male	272 (50.75)	12,041 (51.52)	1 (ref.)		1 (ref.)	
Female	264 (49.25)	11,329 (48.57)	1.03	(0.87 - 1.22)	1.03	(0.87 - 1.22)
<b>Plurality</b>						
Singleton birth	520 (97.01)	22,632 (96.83)	1 (ref.)		1 (ref.)	
Multiple birth	16 (2.99)	741 (3.17)	0.94	(0.57 - 1.56)	0.96	(0.58 - 1.58)
<b>Status at birth</b>						
<b>Live births</b>	534 (99.63)	23,291 (99.65)	1 (ref.)		1 (ref.)	
<b>Stillbirths</b>	2 (0.37)	79 (0.34)	1.10	(0.27 - 4.50)	1.10	(0.27 - 4.50)
<b>Singleton live births</b>			<b>OR</b>	<b>(95%CI)</b>	<b>OR*</b>	<b>(95%CI)</b>
<b>Preterm</b> ( $<37$ weeks)	30 (5.78)	1,226 (5.44)	1.06	(0.731 - 1.54)	1.07	(0.74 - 1.55)
<b>Low birth weight</b> ( $<2.500$ gr)	35 (6.74)	1,226 (5.44)	1.26	(0.88 - 1.78)	1.26	(0.89 - 1.79)
<b>Very low birth weight</b> ( $<1500$ gr)	4 (0.77)	133 (0.59)	1.31	(0.48 - 3.55)	1.31	(0.48 - 3.56)
<b>Small for gestational age</b>	15 (2.89)	616 (2.75)	1.05	(0.62 - 1.77)	1.05	(0.63 - 1.77)

\*OR adjusted for maternal age and infant gender (OR contrasting male and female gender adjusted for maternal age, only)

## Discussion

This retrospective study investigated birth outcomes among women residing near one of the largest Italian solid waste landfills (the Bellolampo MSW-L), who were pregnant during a fire that started on July 29, 2012 and lasted for about a two-week period before being completely extinguished.

As compared to births occurring during the same interval to mothers residing in other areas of Sicily

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3 257 with similar population density and level of industrialization, we observed statistically significant  
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5 258 differences suggesting that the landfill arson could have had an adverse impact on pregnancy  
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8 259 outcomes. Our secondary analysis did not highlight statistically significant differences between the  
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10 260 metropolitan exposed area and the other metropolitan populations in Sicily. In the study group, the  
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12 261 analysis documented a three-fold excess risk of very preterm birth (<32weeks, OR adjusted for  
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14 262 maternal age and infant gender= 3.41; 95%CI= 1.04 - 11.16) and a two-fold excess risk of very low  
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16 263 birth weight (<1500g) among singleton live births. The effect on very low birth weight appeared to  
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19 264 be concentrated among births whose conception date was between 12 weeks prior to the beginning  
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21 265 of the fire to 4 weeks after, suggesting that the largest impact of the exposure may have been on  
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24 266 pregnancies that were conceived during the fire (OR adjusted for maternal age and infant gender=  
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26 267 4.64; 95%CI= 1.04 – 20.6) or were exposed to the fire during the first trimester (OR adjusted for  
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28 268 maternal age and infant gender = 3.66; 95%CI= 1.11 – 12.1). On the other hand, the effect on the  
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31 269 risk of very pre-term birth did not appear to be confined to any particular subgroup at risk. These  
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33 270 findings are compatible with a toxic effect on placentation or early embryo development leading to  
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35 271 restricted intrauterine growth and premature delivery.[18,19] Maternal exposure to ambient  
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38 272 concentrations of air pollutants, particularly to fine particulate matter, has been identified as a risk  
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40 273 factor for preterm birth, low birth weight and SGA births.[20] Multiple studies have documented an  
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42 274 association between fine particulate exposure and preterm birth.[21-23] Exposure to wildfires has  
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45 275 been proposed as a risk factor for preterm birth [20] and reduced average birth weight.[24, 25]  
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47 276 In a multi-site Italian study, maternal exposure to incinerator emissions was associated with preterm  
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49 277 delivery even at very low levels.[7] Moreover, a study conducted in Taiwan concluded that  
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51 278 exposure to emissions from an incinerator generating dioxin had little effects on birth weight and  
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54 279 female birth, but may have a modest effect on gestational age.[8]  
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57 280 The mechanisms proposed to explain the effect of fine particulate exposure on preterm birth include  
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59 281 oxidative stress, pulmonary and placental inflammation, coagulopathy, endothelial dysfunction and  
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282 hemodynamic responses,[20, 26] as well as intrauterine inflammation.[20] Of interest, adverse

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3 283 pregnancy outcomes including pre-term delivery, intrauterine growth restriction and impaired infant  
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5 284 weight gain are associated with exposure to polychlorinated dibenzo-p-dioxins (PCDDs),  
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8 285 polychlorinated dibenzofurans (PCDFs) and dioxin-like PCBs (DL-PCBs).[1] Recently, The  
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10 286 Hokkaido Study on Environment and Children's Health has demonstrated the effects of  
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12 287 environmental chemical exposures (dioxins, polychlorinated biphenyls, organochlorine pesticides,  
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15 288 perfluoroalkyl substances, phthalates, bisphenol A, and methylmercury) on genetically susceptible  
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17 289 populations and on DNA methylation,[27, 28] while other research suggests that exposure to  
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19 290 tetrachlorodibenzo-*p*-dioxin (TCDD) may induce shifts in the immune response that enhance a  
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22 291 proinflammatory phenotype at the maternal-fetal interface, increasing the risk of infection-mediated  
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24 292 preterm birth.[29]

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26 293 The body of published evidence, taken together with the statistically significant excess risk  
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28 294 concentrated in a relatively narrow period of susceptibility, lends credibility to the hypothesis that  
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31 295 the Bellolampo arson adversely affected pregnancies exposed during conception or in the first  
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33 296 trimester, causing an excess of deliveries of very low birth weight infants in the extra-urban area.

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35 297 The study also documented in the same area a significant four-fold excess of stillbirths among  
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38 298 pregnancies that were exposed to the landfill fire during the third trimester. This finding is based on  
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40 299 a total of three stillbirths that occurred in the extra-urban study group, all of which were  
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42 300 concentrated to the subgroup exposed during the third trimester, and it is possible that the observed  
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45 301 excess is due to chance even if it was statistically significant. On the other hand, long-term  
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47 302 exposure to PCBs was associated with increased proportions of miscarriage and stillbirth in animal  
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49 303 studies,[30] and exposure to emissions from solid-waste incinerators was associated with increased  
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52 304 risk of miscarriage in an epidemiologic study in Italy.[31] Thus, the excess of stillbirths to mothers  
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54 305 exposed during the third trimester could be associated with the arson.

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56 306 The excess of multiple births from pregnancies exposed during the third trimester in the study group  
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58 307 is unlikely to be caused by exposure to the landfill fire, as plurality must have been established long  
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3 308 before the arson. The literature provides conflicting evidence on the association between exposure  
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5 309 to air pollution from incinerators and multiple births.[32]  
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8 310 Long-term exposure of the study area to pollutants (independently from the fire) was already known  
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10 311 and was confirmed by the detection of TCCD and heavy metals at concentrations above the limits  
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12 312 permitted by law [33] in sub-soil samples collected by the regional environment protection agency  
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15 313 after the fire.[34] However, the secondary analysis comparing birth outcomes in the same extra-  
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17 314 urban groups in the year before the arson did not highlight any potential effect related to a long-  
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19 315 term exposure to pollutants emitted from the landfill.  
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21 316 The findings of this study should be interpreted in light of some limitations. First, the retrospective  
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24 317 design and the analysis of data from vital statistics do not allow a detailed assessment of the  
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26 318 longitudinal nature of the exposure-response relation, or precise adjustment for potential  
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28 319 confounding. Although environmental monitoring was performed in response to the arson, we had  
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31 320 limited access to the data and could only confirm the increase in air particulate concentrations after  
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33 321 the beginning of the fire. Thus, we could not assess specific exposure levels of individual  
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35 322 pregnancies at multiple points in time. Lastly, as it is often the case in studies of local  
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38 323 environmental exposure events, the outcomes of interest were limited in number, especially when  
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40 324 stratified according to the stage of the pregnancy at exposure. Nevertheless, the observations made  
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42 325 in this study are of general interest. While previous studies conducted in Italy have suggested  
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45 326 associations between exposure to incinerator emissions and increased risk of miscarriages and  
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47 327 preterm births,[31] to our knowledge, the present study is the first in Europe to investigate the  
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49 328 effects of exposure emissions on birth outcomes evaluating pregnancies exposed at different stages  
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52 329 of development. Despite the limited information base and sample size, the excess of very low birth  
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54 330 weight infants achieved statistical significance and was confined to early-stage pregnancies.  
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56 331 The study adds to the growing body of evidence that exposure to emissions from solid waste  
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58 332 landfill operations may have serious health effects and underscores the need for monitoring  
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60 333 potential hazards and health outcomes in the resident population.[35] The arsons at the Bellolampo

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3 334 MSW-L,[36] as well as the ones that occurred in other Italian solid waste treatment plants in  
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5 335 proximity to populated areas,[10] and the public concern they caused, exemplify the important role  
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7 336 that integration of environmental monitoring and epidemiologic surveillance may have in this  
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10 337 realm.[37-39] The questionable strength of the evidence collected in this and in similar studies also  
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12 338 underscores the need for better planning of monitoring and surveillance activities (more detailed  
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14 339 exposure information, better definition and monitoring of reproductive and other health outcomes,  
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17 340 assessment of long-term effects and better control for potential confounders), and highlights the  
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19 341 difficulty of conveying results to the various stakeholders [9] and the related need for effective  
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21 342 methods to transfer study results to policy makers and the public.[40]  
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24 343 Finally, our study highlights the importance to promote an integrated management of urban solid  
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26 344 waste alternatives to landfills, including waste to energy plants or other newly available  
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28 345 technologies such as pyrolysis and gasification.[41]  
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### 30 346 **Ethics**

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33 347 Ethical approval was obtained by the “Palermo Ethical Committee 1” on February 14, 2018  
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35 348 (protocol number: 02/2018).  
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### 37 349 **Data sharing**

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40 350 No additional data available.  
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### 42 351 **Funding**

43  
44  
45 352 No funding received.  
46

### 47 353 **Competing interests**

48  
49 354 The authors declare they have no actual or potential competing interests.  
50

### 51 355 **Authors’ contributions**

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53 356 All individuals listed as authors have contributed substantially to designing, performing or reporting  
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55 357 the study and every specific contribution is indicated as follows. Conception and design of the  
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58 358 study: WM, MM, RC, AC. Data collection: ET, AC, SS. Statistical analysis: ET, AC, RG, MM,  
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60 359 WM. Interpretation of data: CC, CM, WM, MM, AC, ET. Manuscript writing and drafting: WM,

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360 MM, CM, AC, DA. Revision of the manuscript: WM, CM, MM, SS, FV. Approval of the final  
361 version of the manuscript: WM, ET, MM, CM, RC, DA, CC, RG, AC, SS, FV.

### 362 **Acknowledgments**

363 The authors are grateful to the Regional Environmental Protection Agency of Sicily (ARPA Sicilia)  
364 for technical assistance with the study design.

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479 **Figure 1.** Bellolampo solid waste landfill arson: pregnancy stage at exposure among resident  
480 mothers and key statistically significant findings documented for the extra-urban area (the arrows  
481 represent the health outcomes associated to the exposure to the pollutants emitted by the arson).

482  
483 **Supplementary File.** Under surveillance area exposed to emissions deriving from the Bellolampo  
484 municipal solid waste landfill (Borgetto, Capaci, Carini, Giardinello, Montelepre, Torretta):  
485 Metropolitan area (Palermo) and extra-urban area (in red).

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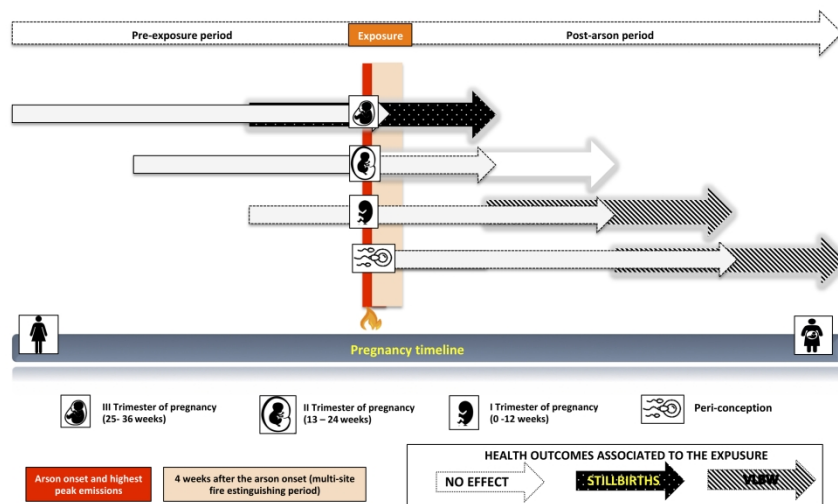
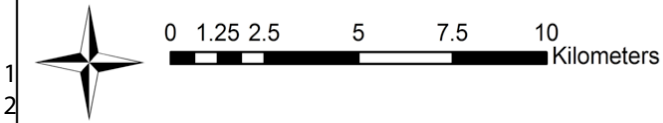


Figure 1. Bellolampo solid waste landfill arson: pregnancy stage at exposure among residentmothers and key statistically significant findings documented for the extra-urban area (the arrows represent the health outcomes associated to the exposure to the pollutants emitted by the arson).

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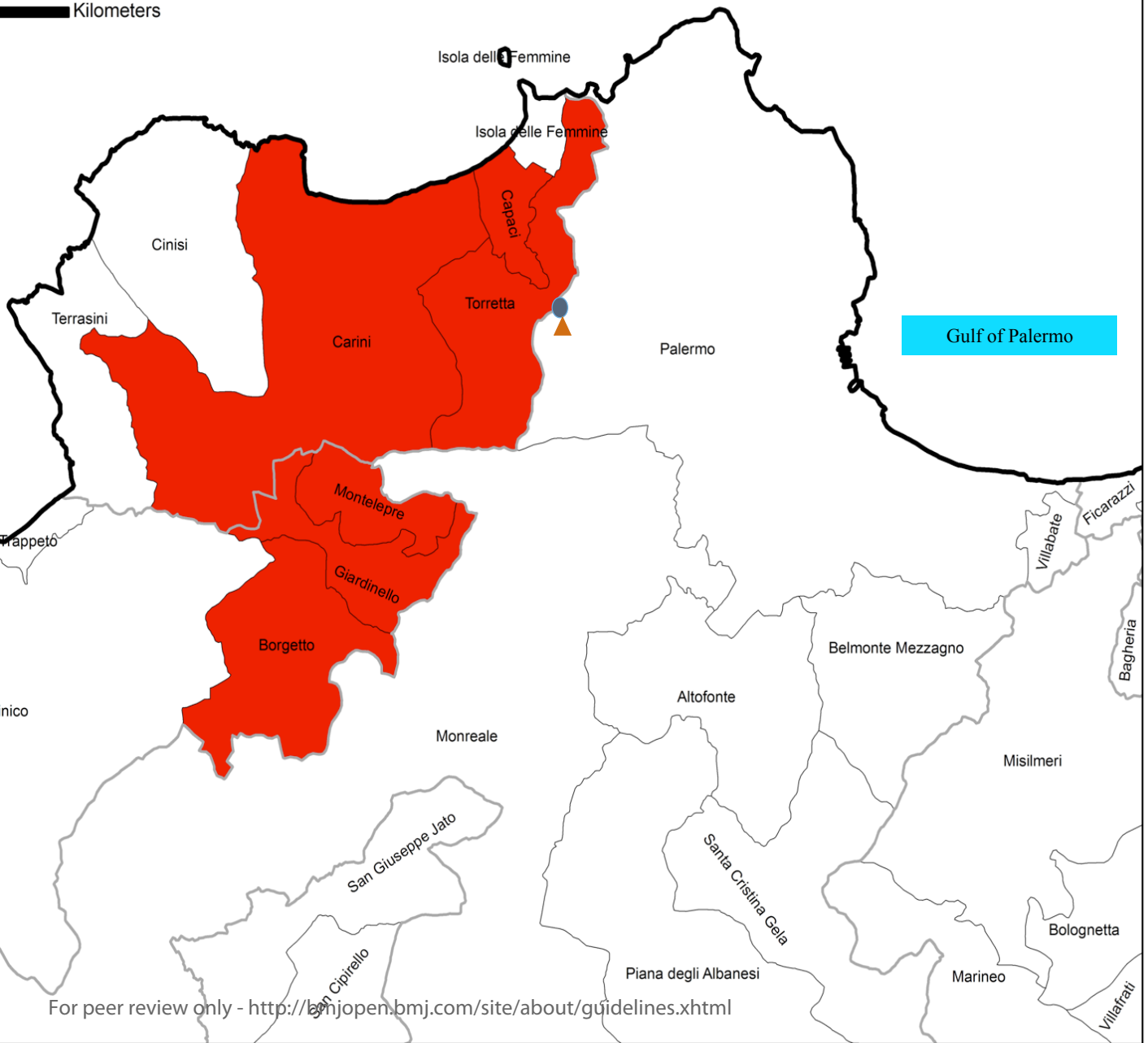


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Mediterranean Sea

Gulf of Palermo

- Bellolampo MSW-L
- ▲ Air monitoring station (Boccadifalco)



Western Sicily

## STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4 - 6
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	4-6
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6
Bias	9	Describe any efforts to address potential sources of bias	5
Study size	10	Explain how the study size was arrived at	4
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5-6
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	5-6
		(b) Describe any methods used to examine subgroups and interactions	5-6
		(c) Explain how missing data were addressed	NA
		(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	NA
		(e) Describe any sensitivity analyses	NA

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<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6-7
		(b) Give reasons for non-participation at each stage	NA
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6
		(b) Indicate number of participants with missing data for each variable of interest	NA
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	7-9
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	NA
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	NA
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	7-9
		(b) Report category boundaries when continuous variables were categorized	9-11
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	11-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13
Generalisability	21	Discuss the generalisability (external validity) of the study results	15
<b>Other information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15

\*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).