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Cancer incidence in the vicinity of open landfills in Guadeloupe, French West Indies

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Abstract

Background People living in the vicinity of a landfill may be exposed to a wide range of pollutants, with possible subsequent health effects, including increased risks of cancer. The aim of the present study was to explore associations between cancer incidence and proximity to the main open landfills in Guadeloupe.

Methods We used data from the Guadeloupe cancer registry over the period from 2008 to 2017. We conducted analyses for the 18 most frequent cancer sites. We used the Besag York and Mollié model to study the association between cancer incidence and distance from a landfill, with adjustment for social deprivation.

Results People who lived less than 2 km from a landfill had increased risks of ovarian and head and neck cancer. Elevated risks of pancreatic cancer, prostate cancer, lung cancer and melanoma in men, as well colon cancer and hormone receptor-negative breast cancer in women, were also observed.

Conclusion A link between exposure to pollutants generated by a landfill and the risk of developing certain cancers was suggested but should be confirmed by additional studies involving a better characterization of exposure and control of potential confounders.

Keywords Cancer epidemiology, Environmental pollution, Caribbean, Landfill, Spatial analysis

Introduction

Waste management is a growing problem around the world, with important implications for the environment as well as for human health and welfare. In the absence of other waste management techniques and because of its lower cost, landfilling is the most widely used method in the Caribbean, although it is considered the least desirable option [1]. This is the case in Guadeloupe, an archipelago in the French West Indies, where open landfills are used for solid waste disposal. Landfills can release a wide range of pollutants into the environment and generate air pollution, including gaseous releases such as methane, carbon dioxide, volatile organic compounds and metal vapors, as well as particulate matter [2–6]. Waste storage also produces leachates that may migrate to the ground and contaminate ground water [7]. People living in the vicinity of a landfill may be exposed to these pollutants through inhalation or contact with contaminated water or soil, directly or through the consumption of contaminated food or water.

The potential health effects associated with residential proximity to landfills have been studied in a number of papers, summarized in several systematic reviews [8–12]. These studies mainly addressed cancer and birth outcomes and, to a lesser extent, respiratory diseases. With

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respect to cancer, increased risks have been reported for various cancer sites, including cancers of the pancreas, liver, stomach, bladder and lung. However, the majority of studies suffer from methodological issues, the results are not consistent across studies, and overall, the evidence remains inadequate.

Spatial analysis in epidemiology can lead to valuable insights into the possible environmental causes of a disease [13]. We previously described the geographical variations in cancer incidence in Guadeloupe, and we found that some high-incidence areas were characterized by the presence of open landfills [14].

The aim of the present study was to explore associations between cancer incidence and proximity to landfills in Guadeloupe.

Materials and methods

Local context

Guadeloupe is a French territory of 1628 km^2 with a population of approximately 400,000 inhabitants. It is a multiethnic population with a majority of people of African descent. The three authorized open landfills operating between the beginning of the 1970s and the end of the 2000s were located at La Gabarre (37 ha), Saint-François (8.6 ha) and Baillif (7 ha). A distinctive feature of these landfills is that they are located in the immediate vicinity of dwellings, in particular the landfill at La Gabarre, which is located in an urban area. Until a change in regulation in 2008, landfills received not only municipal waste but also hazardous waste, including industrial waste, end-of-life vehicles, batteries and accumulators.

Cancer data

We analyzed data collected by the Guadeloupe general cancer registry. Since 2008, the registry continuously and exhaustively records all new cases of cancer occurring in persons residing in Guadeloupe, regardless of age at diagnosis. Several standardized items are systematically collected by the registry for all types of cancer: date of diagnosis, topographical and morphological codes of the International Classification of Diseases in Oncology (ICD-O3), and sociodemographic information (sex, date of birth, and exact address of residence at diagnosis). For breast cancer, patients' status for hormonal receptors is also recorded. As a member of the French Network of Cancer Registries (FRANCIM), the cancer registry of Guadeloupe complies with strict standards; quality and completeness of the data are routinely evaluated by the "Comité National des Registres" (National Registries Committee).

Analyses were performed for the 18 sites with the highest number of cancer cases: head and neck (codes ICD-O3 C00 to C14 and C30 to C32; 604 cases), esophagus (C15; 216 cases), stomach (C16; 863 cases), colon (C18-C19; 1389 cases), rectum (C20, C21; 376 cases), liver (C22; 217 cases), pancreas (C25; 329 cases), multiple myeloma (C42.1 and morphology codes 9731 to 9734; 1260 cases), melanoma (C44 and morphological code from 8720 to 8770; 130 cases), breast (C50; 2342 cases), cervix uteri (C53; 242 cases), corpus uteri (C54; 402 cases), ovary (C56; 195 cases), prostate (C61; 5321 cases), kidney (C64; 242 cases), brain (C71; 140 cases) and thyroïd (C73; 223 cases). Our study was restricted to invasive tumors, diagnosed from 2008 to 2017, with 15,074 tumors in total. We further analyzed breast cancer incidence according to hormonal receptor status in two categories: at least one hormone receptor positive (HR+, 1511 cases) and both hormone receptors negative (HR-, 424 cases).

Statistical analysis

Analyses were conducted at a submunicipality level, the IRIS level. The IRIS, which stands for Ilots regroupés pour l'information statistique (Merged Islet for Statistical Information), is the smallest geographical census unit available in France. In Guadeloupe, there are 136 IRIS. Each patient's address was geocoded to determine their IRIS. Census data for the years 2008–2017 provided the population of each IRIS according to sex and the following age categories: 0–14 years, 15–29 years, 30–44 years, 45–59 years, 60–74 years, 75 years and more.

We estimated the distance to the landfill by calculating the distance between the landfill and the centroid of the IRIS for each IRIS. To study the association between cancer incidence and distance from a landfill, distance categories were introduced in the model as three dummy variables for the categories < 2 km, [2–4[km, [4–6[km, the category ≥ 6 km being set as the reference group. The population living in the vicinity of a landfill is often more deprived than the general population. To take this issue into consideration, we included an index of social deprivation in the model. The construction of this index of deprivation developed for the French West Indies has been described previously in detail [15]. Briefly, the index was built from the 2008 census data at the IRIS level. From an initial a priori selection of 137 social, demographic, and economic indicators, principal component analyses were used to select 8 variables: proportion of unemployed, proportion of blue-collar workers, proportion of managers, proportion of workers with permanent jobs, proportion of people without a diploma, proportion of households without a car, proportion of primary residences with hot water and proportion of primary residences with air conditioning. The deprivation index is defined as the first component of a principal component analysis of these 8 variables. The index was calculated for each IRIS.

Figure 1 shows the 136 IRIS of Guadeloupe, according to the social deprivation index, and the location of the three landfill sites.

We used the Besag, York and Mollié model (BYM model) [16], which is a hierarchical Bayesian model that takes into account both nonspatial heterogeneity and spatial autocorrelation. This model overcomes the problem of small numbers in some areas and allows the inclusion of explanatory variables.

The model is written as follows:

$$\log\theta_{i} = \alpha + u_i + v_i + \delta DI_i + \sum_{j=1}^{3}\beta_{j} X_{ji}$$

where for each IRIS i:

$$\theta_{i} = O_i/E_i$$

O_i is the observed number of cases, E_i is the expected number, $O_i \sim \text{Poisson}\ (Ei\theta\ i)$

α is the intercept

u_i is the nonspatially structured heterogeneity

v_i is the spatially structured heterogeneity and is modeled by a conditional autoregressive model (CAR)

DI_i is the index of social deprivation

X_{ji}: the j-th category of distance from the landfill: X_1 (less than 2 km), X_2 (between 2 km and 4 km), X_3 (between 4 km and 6 km).

$\boldsymbol{\delta}$ the coefficient of the index of social deprivation.

$\boldsymbol{\beta}_{j}$ coefficient related to the j-th category of distance.

The relative risk RR_j was calculated as $RR_j = \exp\left(\beta_{j}\right)$

The relative risk estimates were obtained based on their posterior means, along with the corresponding credible intervals, using Markov chain Monte Carlo algorithms. Since our goal was primarily exploratory, we opted for 80% credible intervals (80% CI). For each model, we ran two independent chains of 240,000 iterations after a burn-in of 60,000 iterations.

The BYM model was implemented with WINBUGS.1.41 and R.4.0.2.

Results

Table 1 shows the RRs and 80% CIs associated with the categories of distance from a landfill for the different cancer sites.

For IRIS located less than 2 km from a landfill, we found significantly increased risks of ovarian (RR = 1.62, 80% CI: 1.15, 2.30) and head and neck cancer (RR = 1.70, 80% CI:

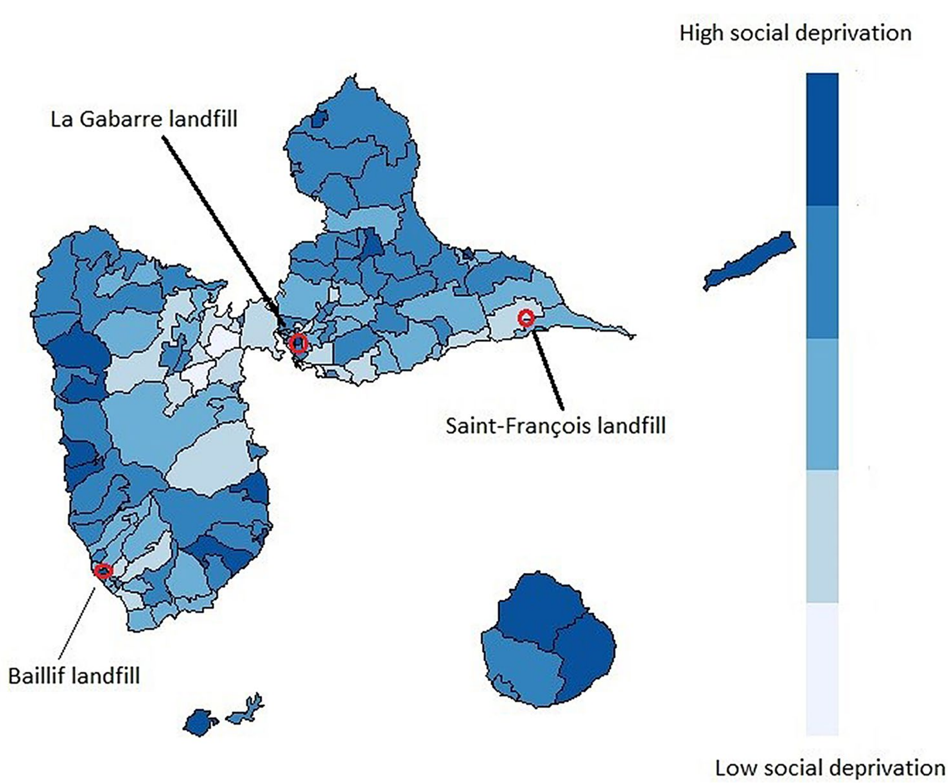

Fig. 1 Map of Guadeloupe showing the 136 IRIS according to the social deprivation index and the location of the three landfills

Table 1 Relative risk of cancer according to the distance from a landfill, by cancer site

		Less than 2 km		2 km to 4 km		4 km to 6 km		More than 6 km	
Cancer site	**Sex**	**N**	**RR (80% CI)**	**N**	**RR (80% CI)**	**N**	**RR (80% CI)**	**N**	**RR (80% CI)**
Head and neck	All	58	1.33 [1.03, 1.70]	108	1.23 [1.02, 1.48]	49	1.09 [0.87, 1.36]	389	1 (Ref)
	Women	5	0.50 [0.23, 1.03]	17	0.97 [0.61, 1.53]	11	1.23 [0.73, 2.01]	66	1 (Ref)
	Men	53	1.70 [1.30, 2.20]	91	1.38 [1.13, 1.69]	38	1.10 [0.85, 1.42]	323	1 (Ref)
Esophagus	All	14	0.79 [0.51, 1.22]	30	0.98 [0.72, 1.35]	10	0.59 [0.37, 1.04]	162	1 (Ref)
	Women	0	-	5	0.73 [0.35, 1.50]	0	-	27	1 (Ref)
	Men	14	1.05 [0.66, 1.64]	25	1.09 [0.76, 1.54]	10	0.78 [0.48, 1.25]	135	1 (Ref)
Stomach	All	55	0.79 [0.62, 1.01]	121	0.94 [0.79, 1.12]	68	1.03 [0.84, 1.26]	619	1 (Ref)
	Women	22	0.74 [0.52, 1.05]	58	1.06 [0.83, 1.34]	27	0.98 [0.73, 1.31]	244	1 (Ref)
	Men	33	0.88 [0.63, 1.21]	63	0.88 [0.69, 1.12]	41	1.05 [0.80, 1.38]	375	1 (Ref)
Colon	All	126	1.16 [0.95, 1.40]	221	1.05 [0.91, 1.22]	109	1.01 [0.85, 1.19]	933	1 (Ref)
	Women	75	1.32 [1.06, 1.63]	113	1.09 [0.92, 1.28]	57	1.09 [0.89, 1.33]	441	1 (Ref)
	Men	51	1.07 [0.79, 1.42]	108	1.04 [0.84, 1.29]	52	0.92 [0.72, 1.19]	492	1 (Ref)
Rectum	All	32	1.13 [0.81, 1.54]	61	1.06 [0.83, 1.34]	29	0.95 [0.71, 1.26]	254	1 (Ref)
	Women	15	1.24 [0.80, 1.90]	25	1.05 [0.74, 1.48]	9	0.69 [0.42, 1.11]	101	1 (Ref)
	Men	17	1.11 [0.74, 1.65]	36	1.09 [0.81, 1.48]	20	1.14 [0.80, 1.62]	153	1 (Ref)
Liver	All	15	0.86 [0.54, 1.34]	31	0.84 [0.61, 1.16]	16	0.81 [0.55, 1.19]	155	1 (Ref)
	Women	2	0.25 [0.08, 0.70]	8	0.68 [0.37, 1.21]	3	0.46 [0.19, 1.05]	48	1 (Ref)
	Men	13	1.27 [0.80, 2.00]	23	0.92 [0.65, 1.3]	13	0.93 [0.61, 1.41]	107	1 (Ref)
Pancreas	All	30	1.20 [0.87, 1.65]	47	0.98 [0.76, 1.25]	25	0.99 [0.73, 1.33]	227	1 (Ref)
	Women	12	0.78 [0.47, 1.26]	22	0.85 [0.59, 1.23]	10	0.77 [0.48, 1.24]	108	1 (Ref)
	Men	18	1.75 [1.18, 2.59]	25	1.08 [0.78, 1.49]	15	1.13 [0.77, 1.66]	119	1 (Ref)
Lung	All	51	1.22 [0.95, 1.57]	93	0.96 [0.79, 1.16]	44	0.85 [0.68, 1.08]	395	1 (Ref)
	Women	18	1.14 [0.77, 1.70]	31	0.90 [0.66, 1.21]	18	0.94 [0.65, 1.33]	139	1 (Ref)
	Men	33	1.34 [0.99, 1.80]	62	1.03 [0.82, 1.30]	26	0.81 [0.6, 1.09]	256	1 (Ref)
Multiple myeloma	All	98	1.06 [0.85, 1.32]	216	1.03 [0.88, 1.21]	105	0.98 [0.82, 1.16]	841	1 (Ref)
	Women	44	1.00 [0.76, 1.30]	93	1.06 [0.88, 1.29]	46	1.02 [0.81, 1.28]	372	1 (Ref)
	Men	54	1.18 [0.87, 1.58]	123	1.07 [0.86, 1.33]	59	0.93 [0.73, 1.17]	469	1 (Ref)
Melanoma	All	10	1.26 [0.75, 2.11]	16	0.70 [0.46, 1.05]	9	0.67 [0.41, 1.10]	95	1 (Ref)
	Women	1	0.16 [0.03, 0.71]	5	0.50 [0.24, 0.97]	5	0.92 [0.45, 1.80]	39	1 (Ref)
	Men	9	2.19 [1.18, 4.06]	11	0.85 [0.50, 1.43]	4	0.46 [0.21, 0.97]	56	1 (Ref)
Breast	Women	199	1.03 [0.87, 1.21]	375	0.99 [0.88, 1.11]	207	1.02 [0.90, 1.16]	1561	1 (Ref)
Breast HR+		119	0.90 [0.82, 1.20]	235	0.93 [0.86, 1.13]	146	1.11 [1.03, 1.38]	1011	1 (Ref)
Breast HR-		41	1.27 [1.09, 2.03]	77	1.23 [1.09, 1.73]	30	0.85 [0.73, 1.30]	276	1 (Ref)
Cervix uteri	Women	27	1.34 [0.94, 1.88]	48	1.35 [1.04, 1.77]	18	0.99 [0.69, 1.4]	149	1 (Ref)
Corpus uteri	Women	42	1.28 [0.96, 1.69]	58	0.91 [0.72, 1.14]	41	1.22 [0.95, 1.55]	261	1 (Ref)
Ovary	Women	24	1.62 [1.15, 2.30]	39	1.43 [1.09, 1.88]	13	0.87 [0.57, 1.28]	119	1 (Ref)
Prostate	Men	422	1.15 [0.99, 1.34]	716	1.00 [0.90, 1.12]	401	1.01 [0.90, 1.14]	3782	1 (Ref)
Kidney	All	17	0.88 [0.59, 1.30]	33	0.85 [0.63, 1.13]	21	1.01 [0.72, 1.41]	171	1 (Ref)
	Women	5	0.66 [0.32, 1.33]	13	1.05 [0.65, 1.69]	7	1.10 [0.61, 1.94]	59	1 (Ref)
	Men	12	1.07 [0.67, 1.69]	20	0.77 [0.53, 1.10]	14	0.97 [0.64, 1.44]	112	1 (Ref)
Brain	All	11	0.88 [0.53, 1.43]	20	0.77 [0.53, 1.11]	6	0.43 [0.23, 0.76]	103	1 (Ref)
	Women	7	1.40 [0.71, 2.73]	14	1.45 [0.87, 2.39]	4	0.72 [0.33, 1.50]	40	1 (Ref)
	Men	4	0.53 [0.24, 1.09]	6	0.37 [0.20, 0.65]	2	0.19 [0.06, 0.51]	63	1 (Ref)
Thyroid	All	11	0.62 [0.38, 1.08]	34	0.97 [0.72, 1.31]	27	1.46 [1.06, 1.99]	151	1 (Ref)
	Women	11	0.71 [0.42, 1.16]	24	0.87 [0.60, 1.24]	24	1.67 [1.17, 2.37]	117	1 (Ref)
	Men	0	-	10	1.20 [0.70, 2.01]	3	0.56 [0.24, 1.29]	34	1 (Ref)

1.30, 2.20), as well as pancreatic cancer in men (RR = 1.75, 80% CI: 1.18, 2.59), melanoma in men (RR = 2.19, 80% CI: 1.18, 4.06) and colon cancer in women (RR = 1.32, 80% CI: 1.03,1.63). Elevated borderline significant RRs were also observed for prostate cancer (RR = 1.15, 80% CI: 0.99, 1.34) and lung cancer in men (RR = 1.34, 80% CI: 0.99, 1.80).

For head and neck and ovarian cancer, the relative risk decreased with increasing distance to the landfill but remained elevated for IRIS located between 2 km and

4 km from a landfill. The association between head and neck cancer and distance from the landfill was limited to men. For prostate cancer, pancreatic cancer, melanoma, and lung cancer in men and colon cancer in women, the relative risks were not significant beyond 2 km from a landfill.

The incidence of breast cancer overall was not associated with the distance from a landfill. However, when stratified by hormonal status, an increased risk of HR- breast cancer was observed for IRIS located less than 2 km from a landfill (RR = 1.27, 80% CI: 1.09, 2.03) and those located between 2 and 4 km from a landfill (RR = 1.23, 80% CI: 1.09, 1.73). The relative risks decreased when moving away from the landfill. For HR + breast cancer, the relative risks were not significantly different from 1. The incidence of cervical cancer was elevated for IRIS located less than 4 km from a landfill, although the RR was only significant for a distance between 2 km and 4 km (RR = 1.35, 80% CI: 1.04, 1.77).

Beyond 4 km from a landfill, no significant increase in risk was found for any cancer site.

Discussion

In this study, we found increased risks of several cancer sites in the vicinity of landfills in Guadeloupe.

The nature and level of pollutants emitted by landfills depends on the type of waste, climatology, and immediate environment of the landfill and can vary considerably from one landfill to another. The data available for Guadeloupe only concern the main landfill, La Gabarre. Previous studies carried out around this landfill reported pollution with nitrogen oxide, ozone, sulfur dioxide, carbon monoxide, methane, and volatile organic compounds (VOCs), such as chlorobenzene, benzene, ethylbenzene, trichloroethylene, tetrachloroethylene and acetaldehyde, up to 3 km from the landfill [4, 17–19]. Several of these pollutants have been linked with cancer risk. Benzene [20] and trichloroethylene [21] are classified as carcinogenic to humans by the International Agency for Research on Cancer. Tetrachloroethylene [21] is classified as probably carcinogenic, while ethylbenzene [22] and acetaldehyde [23] are possible carcinogens. Nearby sites downwind of the landfill plume had the highest concentrations, but under certain atmospheric conditions, most of the surrounding area, downwind and upwind, exhibited elevated VOC levels. No measurements were available for the other landfills, although it is reasonable to assume that the surrounding areas were also impacted by landfill pollution. It should be noted that an excess risk of preterm birth, an outcome related to landfill vicinity, was previously reported around the Saint-François landfill [24].

In our study, we found an increased risk of cancer of the pancreas in men living less than 2 km from a landfill. A case-control study conducted in Canada also suggested an increased risk of developing pancreatic cancer for men living near a landfill: after adjustment for key confounders, elevated risks were found for cancer of the pancreas in the exposure zone nearest to the site, as well as using distance from the site as another exposure metric [25]. In a retrospective cohort study conducted in Finland among inhabitants of houses built in a former dump area, an excess risk of pancreatic cancer was also reported among men only [26]. In another study, an increased risk of being hospitalized for exocrine pancreatic cancer was associated with residential exposure to VOCs and persistent organic pollutants arising from hazardous waste sites. An analysis of specific chemicals in the same study showed elevated rate ratios for exposure to benzene, ethybenzene, trichloroethylene, tetrachloroethylene, chlorinated pesticides and PCBs [27].

We found an association between the incidence of head and neck cancers and the proximity of landfills. This association has rarely been investigated. A study conducted in Malagrotta, Italy, showed a significant decrease in laryngeal cancer mortality with distance from an area with several sources of pollution: a landfill, an incinerator and a petrochemical plant. This decline in mortality remained after adjustment for socioeconomic status [28]. A more recent study in the same area used the concentration of hydrogen sulfide (H_2S), modeled by an air dispersion model, as a tracer of the pollution generated by the landfill. H_2S exposure was associated with an elevated risk of laryngeal cancer mortality in women but not in men [29]. In addition, associations between head and neck cancer and several pollutants potentially released from landfills have been reported. Exposure to fine particulate matter air pollution was found to be associated with oral, pharyngeal or laryngeal cancer [30–32]. A possible impact of exposure to trichloroethylene and tetrachloroethylene on the occurrence of head and neck cancers was also suggested [33, 34].

In the majority of studies that addressed cancer risks in the area surrounding landfills, results on ovarian cancers were not presented. The excess risk of ovarian cancer that we observed in the vicinity of landfills is, however, consistent with the high risk of mortality from ovarian cancer observed in Spain in towns located less than 5 km from hazardous waste treatment installations [35]. Another study in Spain showed an association between ovarian cancer mortality and the proximity of a variety of industrial sites, including waste treatment plants [36]. More generally, exposure to ambient air pollution has been found to be associated with increased risks of ovarian cancer [37].

In our study, the increased risk of melanoma in the proximity of landfills observed in men diverged from the inverse association found in women, based on only one case. The aforementioned study in Finland reported an excess risk of skin cancer (melanoma and nonmelanoma combined) in men who had lived in the former dump area, while there were no cases of these cancers among women [26]. An increased mortality from skin cancer was also found in men but not in women in Spanish towns situated within 5 km of hazardous waste installations [35]. PCBs are a recognized cause of melanoma [38], but other ambient pollutants, such as VOCs, heavy metals, PAHs, and PM, have been shown to impact skin tumorigenesis through various mechanisms, and for PAHs, the impact seems to be aggravated by UV radiation [39].

We found an elevated risk of colon cancer near the landfills in women only. Overall, the literature does not provide strong support for the existence of an association between colon cancer and landfill proximity. In studies specifically addressing colon cancer, no excess risk was observed near landfills [25, 40]. Two studies suggested an association with colorectal cancer but did not distinguish between colon and rectum [26, 35].

Our study also suggests an increased risk of lung cancer among those who lived near landfills. A significant positive association between landfill H_2S exposure and mortality from lung cancer was found in a cohort study in Italy. In this study, exposure to H_2S, modeled by an air dispersion model, was used as a surrogate measure of all pollutants emitted by the nine landfills in the area [41]. An excess risk of lung cancer in the proximity of hazardous waste installations was also reported in Spain [35].

We found a modest nonsignificant increase in the risk of prostate cancer in the proximity of the landfills. A similar association has been previously reported in Canada [25, 41], whereas another study in New York state did not find any association [39].

We found no association between proximity to a landfill and breast cancer incidence overall, a finding in line with previous knowledge [10–12]. However, stratified analysis by hormone receptor status showed a higher risk of HR- breast cancer in the vicinity of landfills. No study specifically addressing the proximity of landfills has considered hormonal status. Studies investigating air pollution in general provide limited evidence of an association with breast cancer, and whether this association differs according to hormone receptor status remains to be assessed [42, 43].

The main limitations of our study are related to the study design, misclassification of exposure and confounding factors. We used the BYM model to account for both spatially structured and spatially unstructured heterogeneity. Although ignoring real spatial variability leads to a significant bias, it has been suggested that when spatially structured extra-variability does not exist conditionally on the covariates included in the model (over-fitting), the estimate of the ecological association between covariates and relative risks may be biased toward the null. However, a simulation study showed that even in extreme scenarios, the BYM model estimates ecological associations with little bias [44]. As in all ecological studies, the observed associations cannot be interpreted as causal relationships at the individual level. We did not have information on the type and amount of pollutants generated by the landfills. We therefore used distance from landfills as a proxy of exposure, which probably led to misclassification. Although it seems reasonable to assume that people living near the landfill are more exposed than people living farther away, the use of distance as a measure of exposure also assumes that the pollution generated by landfills spreads uniformly around the site, which is unlikely to be true. Recent studies have used air dispersion models that allow for a finer characterization of atmospheric pollution near landfills [41]. A model of this type was used to estimate biogas emissions around La Gabarre [18]. However, input data required to run such models for the three landfills over the study period are not available. On the other hand, the use of distance as a proxy has the advantage of encompassing different exposure pathways (air but also soil or groundwater contamination near the landfill). The use of centroids of the IRIS as coordinates to calculate the distance is another source of exposure misclassification. We had no data on residential history, so exposure was assessed from the address at the time of diagnosis. Possible migration in or out of the exposed areas may have biased the results. However, such migration is probably not related to the incidence of the different cancer sites. Furthermore, due to the lack of information on residential history, we could not account for the duration of residence in the exposed areas. This study was unable to control for individual-level risk factors for cancer incidence. Potential confounders include smoking, alcohol consumption, dietary patterns, and occupational and other environmental exposures. Finally, some findings may be due to chance, as we performed a number of statistical tests and used 80% credible intervals. However, as our aim was primarily exploratory, we considered adjustment for multiple testing as inappropriate.

Our study also has several strengths. Landfills started operating in the early 1970s, so the latency period is long enough for solid tumors. We used a population-based cancer registry to identify incident cases, which provided accurate information on the diagnosis of incident cases and was more reliable than mortality data. We were able to perform a comprehensive analysis of a number of cancer sites, thanks to the exhaustive collection of incident cases during the study period. We were able to adjust for socioeconomic status via a composite deprivation index specifically developed for the population of the French

West Indies. Since many lifestyle risk factors, such as smoking, alcohol consumption and diet, are associated with socioeconomic position, it is reasonable to assume that the adjustment for the deprivation index also provided, in an indirect way, some control of the main risk factors for cancer. This is supported by the consistency of the relationship between deprivation and cancer incidence [15] with the social distribution of cancer risk factors [45].

Conclusion

This study highlighted a possible link between exposure to pollutants generated by landfills and the risk of developing certain cancers in Guadeloupe. The findings are on the whole consistent with other studies in the literature. However, they need to be confirmed by etiological studies, which would control for key confounders and would involve a better characterization of exposure.

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Author contributions
Conceptualization, BB, DL and JD; formal analysis, BB; writing, original draft preparation, BB; writing, review and editing, DL and JD; supervision, DL and JD; funding acquisition, JD. All authors have read and agreed to the published version of the manuscript.

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Data availability
The datasets analyzed for the current study are available from the corresponding author upon reasonable request.

Declarations

Institutional review board statement
The cancer registry of Guadeloupe is authorized by the French Data Protection Authority, Commission National Informatique et Liberté (CNIL), authorization N° 909113 of June 29, 2009. This study obtained ethics approval from the local research ethics committee of the University Hospital of Guadeloupe "Comité éthique CHUPPA" under the registration number A77_14_02_2022_ANSPACAGU. The privacy impact assessment was vetted by the data protection officer of the University Hospital of Guadeloupe (dpo@chu-guadeloupe.fr) in accordance with the General Data Protection Regulation (GDPR). The study was performed in accordance with the Declaration of Helsinki.

Informed consent
Given their public health mandate, French cancer registries are authorized by the French Data Protection Authority "Commission National Informatique et Liberté" (CNIL) to collect data on cancer cases with a waiver for written informed consent (CNIL deliberation n°03–053 of November 27, 2003). Patients' information is given by notices displayed in health care facilities, their attending physician or specialist. General information is also available on the National Cancer Institute website: http://lesdonnees.e-cancer.fr/Informations/Sources/Notice-d-information-generale.

Competing interests
The authors declare no competing interests.

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