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ENVIRONMENTAL POLLUTION IN THE MEZQUITAL VALLEY AND ITS ASSOCIATION WITH CANCER; A CASE STUDY, MEXICO

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ABSTRACT

The inhabitants of the agricultural zone of the Mezquital Valley are environmentally affected by the presence of wastewater and stationary sources of pollution (SSP), which generate greenhouse gases (GHG). It is necessary to identify and implement preventive measures as various chronic degenerative diseases, such as cancer, are caused by these factors. This study intended to analyze the association and perception of wastewater and SSP, as pollutants that cause various types of cancer. In the study region, two communities with differences in terms of their environment and the presence or proximity of wastewater and SSP were compared: San Bartolo Doxey (SBD) and Santa María Macuá (SMM). In these communities, land use and the geographic location of SSP were analyzed. A survey with a structured questionnaire was also designed, validated, and applied, contemplating social and environmental variables and types of cancer occurring among families. In SBD, 83.2% of agricultural land is irrigated with wastewater (SMM has none) and is also located closer to the sources of pollution (approximately 9.3 km) whereas SMM is (approximately 22.0 km). Compared to SMM, SBD has a 72%, 16%, 79%, and 90% higher incidence of cervical, breast, lung, and other cancers, respectively; furthermore, over the last four generations, it has manifested a 63% higher incidence of various types of cancer. There is a certain correlation and perception between wastewater and air pollution, and the incidence of cancer. The most common cancers and those with a known link to pollution are lung and breast cancer.

Key words: cancer, environmental pollution, greenhouse gases, wastewater.

INTRODUCTION

The Mezquital Valley (Valley of Mexico) is one of the ten geographic regions that make up the state of Hidalgo in Mexico. Agricultural development is commonly dependent on the use of wastewater (Martínez, 2018). Air, soil, and water pollution from wastewater and industry worsened in the mid-1970s with the discharge of sewage and industrial wastewater from the Valley of Mexico, from the Miguel Hidalgo refinery and the thermoelectric power plant conglomerations (SEMARNAT, 2020). The Tula-Tepeji industrial park comprises the municipalities of Atitalaquia, Mixquiahuala, Tula de Allende, Atotonilco de Tula, Tlaxcoapan, Tepeji del Río de Ocampo and Tlahuelilpan. Since the 1960s, various industries have become established in this area, and today they are among the most important in Mexico. These include the combined cycle power plant in Tula de Allende, operated by the Federal Electricity Commission (CFE); the cement plants Fortaleza, Cemex, Cruz Azul, and Tolteca; the Miguel Hidalgo refinery of Petróleos Mexicanos (PEMEX); and the chemical industry that is intrinsic to refining (Conagua, 2013; Martínez, 2018; Guerrero and López, 2020).

The Intergovernmental Panel on Climate Change (IPCC) has categorized these industries as the main sources of greenhouse gases (GHGs), whose emissions result in climate change. The secondary effects of climate change, directly or indirectly affect human health. Furthermore, in the state of Hidalgo, it has been proven that some GHGs are triggers for cancerous diseases (Cuadros, 2017).

The residents of the Valley of Mexico suffer daily from the devastating effects of water and air pollution. This pollution manifests itself in the form of intense and pungent odors, comparable to sulfur and burning plastic, causing burning eyes and irritation of the upper respiratory tract. Likewise the population and their domestic animals suffer from constant discomfort due to *Culex* mosquito bites, which primarily breed in sewage. Similarly, in the medium and long term, this pollution takes its toll in the form of chronic degenerative diseases and cancer in its various manifestations. Wastewater discharges from the aforementioned industries, as well as those originating from the Metropolitan Area of the Valley of Mexico, flood the agricultural soils of the Valley of Mexico and contaminate groundwater (with coliform bacteria, arsenic, fluorides and lead, in concentrations exceeding maximum permissible limits) (Lesser *et al*. 2018).

In this regard, studies of communities with varying degrees of pollution in the area and their relationship to cancer, along a generational timeline (grandparents, parents, children, and grandchildren) or after decades of pollution, will help to demonstrate the magnitude of the problem. This research is the first to estimate the relationship between cancer and wastewater and air pollution in the vicinity of the Tula municipality. This study, along with others conducted in the region, will contribute to supporting public policies that translate, on one side, into concrete actions to prevent various types of cancer among the residents of the Valley of Mexico and also into efforts consistent with and aligned to the recent decree by the Federal Executive Branch (2024), which declares the area of influence of the Endho Dam an ecological restoration zone.

Thus, this work aimed to analyze the association and perception of wastewater and SSP as pollutants that cause various types of cancer. The above is based on the hypothesis that soil, water and air pollution caused by wastewater and the generation of some GHGs by SSPs is related to the incidence of various types of cancer in the study region.

THEORETICAL FRAMEWORK

According to the World Health Organization (WHO) (2024a), cancer is a broad term used to describe a group of diseases that can originate in almost any organ or tissue of the body, when abnormal cells grow uncontrollably. The most common cancers include breast, lung, colorectal, prostate, stomach and liver. Although there is a genetic component to its manifestation, air and water pollution from industrial waste and exposure to pesticides used in agriculture are closely linked to a higher risk of developing some types of cancer (Cuadros, 2017; WHO, 2024b).

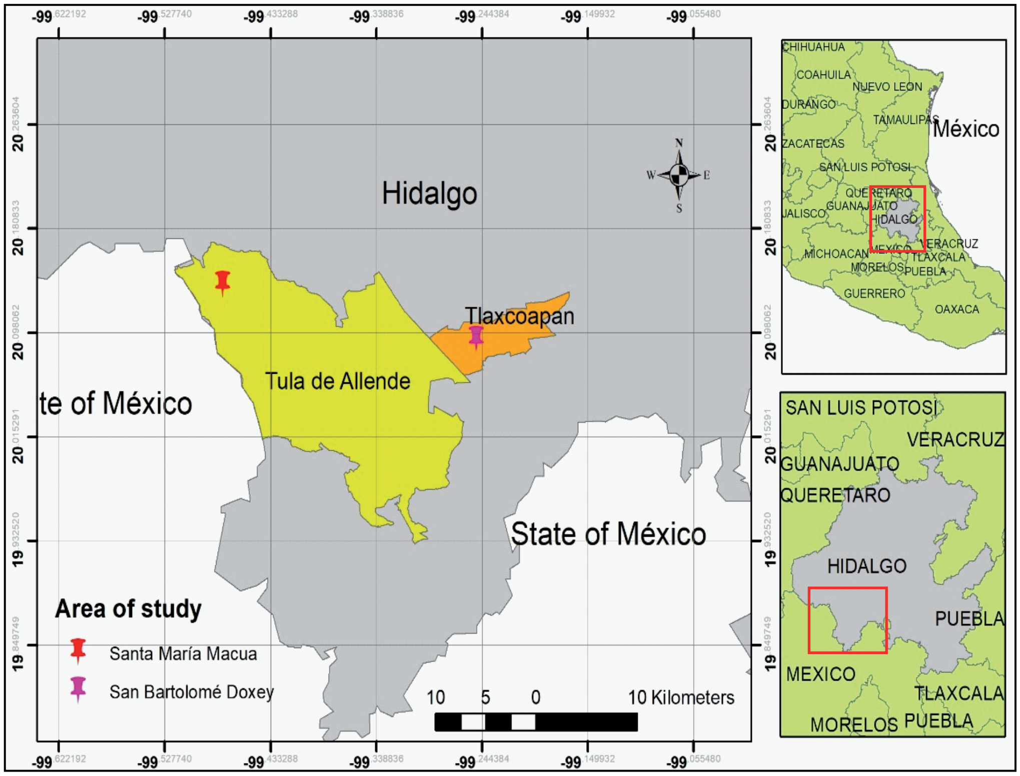
It has been documented that wastewater containing organic and industrial waste, agrochemicals, and metals has contributed to a process of contaminant accumulation in soil, surface water and groundwater that has ecotoxic potential. Furthermore, there is a strong correlation between this type of wastewater and the incidence of breast cancer and endocrine disruption (Cajuste *et al*. 1991; Evangeleu *et al*. 2016; Du Plessis *et al*. 2023). Studies of pollution and how it relates to cancer in this region include those by Prieto *et al*. (2015), concerning the concentration of metals from wastewater, including Cd, Cr, and Pb found in blood, urine, nails, and hair, and those by Martínez (2018), on the incidence of cancer and the link to pollution from cement industries; likewise from Guerrero and López (2020), indicating the probability of the increase in the number of cancer cases, due to the high concentration of greenhouse gases, mainly SO_2, CO_2, NO, CH_4 and N_2O.

Regarding the methodology used to collect information on the types of cancer suffered by the respondents' relatives (four generations) and the communities' perception of the level of pollution in their environment, this was undertaken using a pre-designed questionnaire. Our methodology was based on the work by Rodríguez-Zúñiga *et al*. (2023a): transmission of herbal knowledge and its benefits; Rodríguez-Zúñiga *et al*. (2023b), related to the practice of midwifery and the use of medicinal plants; and Rodríguez *et al*. (2025), breastfeeding and traditional medicine. All of these studies were conducted in the Mazahua Otomi community in the states of Hidalgo and Mexico. Furthermore, most of the respondents (third generation) had living parents (second generation) and grandparents (first generation), and if not, they had knowledge about causes of death. In these studies, curves or functions were constructed for the number of known medicinal plants, the percentage of births per midwife, and breastfeeding periods, respectively. All three research projects considered four generations as the indicator variable. Also noteworthy are the studies by Estrada *et al.* (2016) and Rosas and García (2023) concerning the perception of pollution in the study area: the former focusing on the impact of living near wastewater channels, and the latter on environmental quality due to the use of wastewater by agricultural producers; both in the Mezquital Valley, Hidalgo. These studies revealed that the community perceived their health to be at risk due to proximity to wastewater bodies and poor-quality agricultural production. In this sense, perception is considered to represent the social deductions and interpretations that individuals make, so as to provide a more objective understanding of how people view their natural environment (Fernández-Moreno, 2008).

METHODOLOGY

The research was conducted in the Mezquital Valley (Valley of Mexico) region, in western Hidalgo State. The research approach was exploratory, comparing two communities suffering from varying degrees of environmental pollution. These communities were San Bartolomé Doxey (SBD) and Santa María Macua (SMM), located in the municipalities of Tlaxcoapan and Tula de Allende, respectively (Figure 1). The research techniques employed were observation, structured surveys, and interviews. Based on the defined objectives, observation permitted the identification of urban infrastructure (street paving, drainage discharges into irrigation canals), economic activity (agriculture, irrigation systems, and industry), and the environment surrounding the study communities (native vegetation and water bodies). The structured surveys and interviews provided data on social, economic, and health aspects.

The survey, carried out by applying a questionnaire, was validated in the field or study communities. Necessary adjustments were made, and the questionnaire was randomly applied to adults (mother or father), who had children in their homes. It included closed-ended questions for statistical data and open-ended questions for supplementary information, gathering both quantitative data (age, average monthly income of the head of household, number of children, etc.) and qualitative data (occupation, types of cancer cases registered in the family, perception of the overall level of pollution in their community, type of water used to irrigate their plots, etc.). Based on the most common cancer types reported by the WHO (2024a), the questionnaire was structured using a set of questions to gather information on close family history of the disease, including information from the interviewee's (third generation: father or mother), their offspring (fourth generation: sons or daughters), their parents (second generation: maternal grandfather and maternal grandmother), and their grandparents (first generation: maternal great-grandmother, paternal great-



Source: self-elaborated.

Figure 1. Location of the study area in the Municipalities of Tula de Allende and Tlaxcoapan in the state of Hidalgo, Mexico.

grandmother, maternal great-grandfather and paternal great-grandfather). Fieldwork was conducted in November-December 2024 and January 2025. The database, previously created in Microsoft Excel, was analyzed using the IBM SPSS Statistics software package (V.25.0, 64-bit edition), employing univariate (ANOVA) and multivariate (MANOVA) techniques. This was in order to analyze the normal distribution of data ($p>0.05$) and significant differences between both communities ($p>0.05$) (Infante and Zarate, 2012).

For each settlement, a structured survey was administered using simple random sampling without replacing heads of household, based on the total number of households in both communities, according to the latest population and housing census by the National Institute of Statistics, Geography and Informatics (INEGI) (2020a). The formula devised by Infante and Zárate (2012) (Equation 1) was used for this purpose. The confidence level was 95% and the margin of error was 5%. A total of 122 questionnaires were applied to SBD and 146 to SMM, representing increases of 188% and 241%, respectively, based on the n that was calculated (SBD: n= 65; SMM: n= 61).

$$n = \frac{NZ_{\alpha/2}^{2}pq}{(N-1)d^{2} + Z_{\alpha/2}^{2}pq} \quad (1)$$

where n: sample size; N: population size (N_1 (SMM Community = 647 households; N_2 (SBD Community = 1885 households); $Z_{2\alpha/2}$: value from Z distribution tables ($Z_{2\alpha/2}$=2.6896); p: proportion of the population with a binomial distribution, q=1-p (pq=0.25); d_2: desired maximum absolute error (set as a fraction of p) (10%) (d^2=0.01).

Once the above parameters had been established, there were three stages to this research work:

1. Analysis of land use and main stationary sources of pollution. To study the natural environment of the two case studies (agricultural lands with permanent irrigation using wastewater or seasonal irrigation, natural vegetation, and pollution sources such as cement plants or a refinery), the vector dataset from the Land Use and Vegetation Map Series VII of their ejidos (2013) was used, reclassified for each case into agricultural use, human settlements, and vegetation type (2021). Likewise, for each community within a 32 km radius, the nearest stationary sources of atmospheric pollution and wastewater bodies were identified, according to the Government of the State of Hidalgo (2016). For this purpose, the straight-line distance between the centers of the communities and the stations was measured. Map creation and data analysis were performed using ArcGis® 9-ArcMap TM Version 9.2.
2. Generational Cancer Incidence. Designed, using questions about cancer cases across four generations in the respondents' families (grandparents, parents, children, and grandchildren), two comparative curves or functions (% of cancer cases with respect to generations) were constructed for the communities of San Bartolomé Doxey (SBD) (f(i)) and Santa María Macua (SMM) (f(g)). This was undertaken to determine the excess or degree of incidence of cancer types among these generations (Equation (2)).

$$\%\Delta_{dic} = \int_{a}^{b} \left(f(i) - f(g) \right) dx \quad (2)$$

where $\%\Delta_{dic}$: % difference in cancer incidences; f(i): % function of cancer incidence, with respect to generations of the SBD community; f(g): % function of cancer incidence, with respect to generations of the SMM community.

3. Alignment of supplementary information and perceptions. Data screening was conducted to obtain relevant information, such as: degree of poverty, backyard food farming practices and perceptions (regarding community pollution, the most frequent cancer, and the relationship between cancer and pollution). The set of variables was statistically analyzed to determine significant differences between the two communities. This information contributed to the discussion of results, primarily by providing a better understanding of the relationship between pollution and cancer incidence.

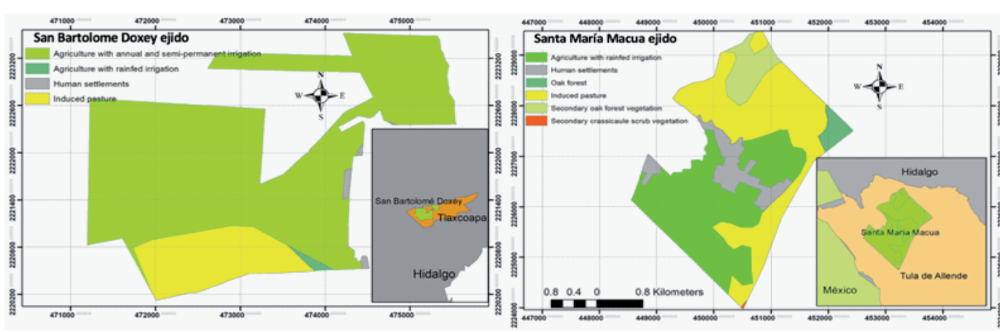
RESULTS

Analysis of land use and stationary sources of pollution

Figure 2 and Table 1 graphically and respectively present the distribution and summary of land use, as well as the distance from the main sources of pollution. The following points are noteworthy: 1) In SBD, 83.26% of agricultural soils are irrigated with annual (or rain-fed) and semi-permanent water (rain-fed as well as constant irrigation with wastewater), with only 0.56% destined to rain-fed agriculture. In contrast, in SMM, 45.9% is destined to rain-fed agriculture, with no plots under annual or semi-permanent irrigation; and 2) SMM still has remnants of typical Valley of Mexico vegetation, namely secondary oak and scrassicaule scrub vegetation. Finally, with the exception of the Endho Dam (3.0 km closer to SMM than SBD), SBD is on average closer to the polluting sources than SMM, at 9.3 km (ds 3.329) and 22.0 km (ds 7.74) from the SSP, respectively.

Generational Cancer Incidence

Figure 3 presents cancer incidence among four generations (great-grandparents, grandparents, parents, and children) and the most common variants of the



Source: self-elaborated.

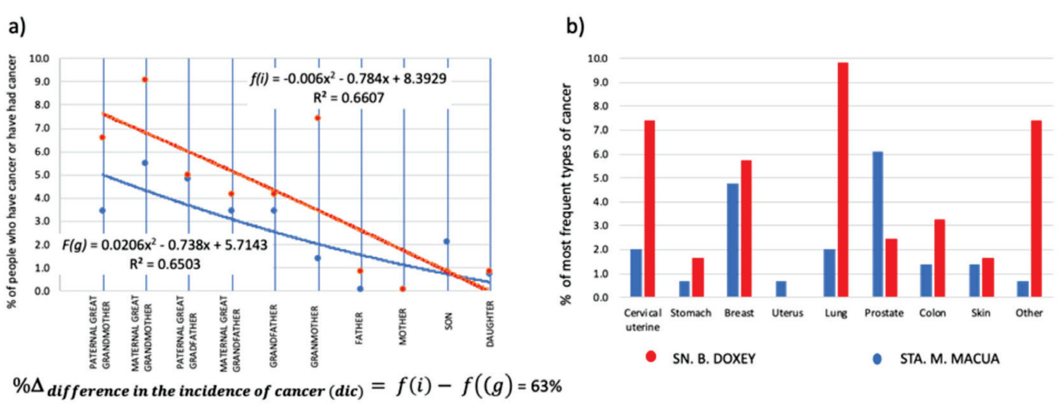
Figure 2. Land use map of the Santa María Macua and San Bartolomé Doxey ejidos, Hidalgo State.

Table 1. Land use area in the SB Doxey and SM Macua ejidos and distances from the main sources of pollution.

Description	San Bartolomé Doxey		Santa María Macua	
	Distance (km)			
Thermoelectric	5.1		22.5	
Refinery	6.5		22.6	
Cruz Azul Cement works	8.5		16.0	
Fortaleza Cement works	10.5		33.5	
Tolteca Cement works	12.5		18.1	
Cemex	8.0		30.1	
Endho Dam	14.5		11.5	
	Surface area (ha)	Surface area (%)	Surface area (ha)	Surface area (%)
Annual and semi-permanent irrigated agriculture	630.807453	83.26		
Annual rain-fed agriculture	4.209304	0.56	406.324867	41.95
Human settlements	5.040684	0.67	88.953154	9.18
Induced pasture	117.616972	15.52	378.957637	39.12
Secondary oak forest vegetation			68.394844	7.06
Secondary crassicaule scrub vegetation			0.509042	0.05
Total	757.674413	100	968.603144	100

Fuente: self-elaborated.

disease. Section a) indicates that: 1) there are significant differences (p>0.05) between the two curves. The SB Doxey function (f(i) in red) is higher than that of SM Macua (f(g) in blue) and, in percentage terms (difference of the areas under the curve, (see Equation 2), there are 63% more cancer cases; 2) in the SB Doxey community, the majority of cases (42%) are recorded among maternal



Source: self-elaborated.

Figure 3. Incidence of generational cancer in the communities of S. B. Doxey and S. M. Macua.

great-grandmothers (23%) and grandmothers (19%); and 3) by gender, in SB Doxey, 61% are among women and in SM Macua, 45%. Section b) graphically shows the most common types of cancer recorded in four generations. In SB Doxey, 78% of cases correspond to lung, cervical, other, and breast cancer (29%, 19%, 19%, and 15%, respectively), while in SM Macua, 75% are prostate, breast, cervical, and lung cancer (31%, 24%, 10%, and 10%, respectively). There is a significant difference in the rates of other cancer types in SB Doxey (7%) compared to SM Macua (0.7%). Finally, SBD, compared to SMM, has a higher percentage of cervical, breast, lung, and other cancer cases: 72%, 16%, 79%, and 90% more, respectively.

Alignment of supplementary information

Table 2 summarizes some of the main variables in the study. There are significant differences ($p>0.05$) in terms of the average income of heads of household and in general (considering all variables) between both communities ($p>0.05$). The

Table 2. Social and environmental variables.

Variables		Sn. B. Doxey	Sta. M. Macua
Average monthly income of the head of household (average/desv. est.)		6,462/4,423	4,854/2,691
Family or backyard gardens for domestic consumption (n/%)	Yes	27/22	79/54
	No	95/78	67/46
Type of water used to irrigate family or backyard gardens	Domestic	2/7	77/98
	Sewage	24/84	1/1
	Both	1/9	1/1
Perception of the level of pollution in your community (n/%)	Very high	34/28	15/10
	High	56/46	54/37
	Low	1/1	16/11
	Moderate	31/25	61/42
Family history of cancer (n/%)	Yes	36/29	34/23
	No	87/71	113/77
Perception of the most frequent cancer in your community (n/%)	Cervical	14/ 14	12/10
	Stomach	3/3	0/0
	Breast	59/59	63/53
	Uterus	0/0	0/0
	Lung	12/12	5/4
	Prostate	4/4	24/20
	Rectum or colon	2/2	0/0
	Skin	2/2	3/3
	Other	5/5	11/9
Perception of contracting cancer due to pollution in their community (n/%)	Very high	18/15	10/7
	High	52/43	60/41
	Medium	41/34	53/36
	Low	11/9	23/16

Source: self-elaborated.

average income of SMM is 15% lower and more homogeneous compared to that of SBD (standard deviations: 2,691 and 4,423 respectively). Regarding backyard farming practices and environmental perception in SMM and SBD: 1) in the former, there is greater awareness of this practice (32% more) and almost all of them (98%) use domestic water; of the few family gardens in SBD, 84% are irrigated with wastewater and the remainder, almost in the same proportion, with domestic water (7%) and mixed water (9%); 2) In that same order of communities, in the first, there is a greater perception of pollution in their community: 75% consider pollution to be high (46%) to very high (28%), compared to 53% who consider it to be low (11%) to moderate (42%). Regarding the topics of cancer and perception of the disease in SBD and SMM, and in that order: in both cases, an average of 23% have a family history of cancer, with 6% more in the first community; both regions perceive that more than 50% of cancer cases in their communities include breast cancer (59% and 53.4% respectively); and 9% more in the SBD community, compared to SMM, believe they may contract cancer as a result of pollution in their community.

DISCUSSION

An analysis of land use corroborates the respondents' answers regarding the type of water they use to irrigate their orchards and crops in general. The SBD community is immersed in an agricultural irrigation system using wastewater (Agrarian Nucleus I, Tlaxcoapan, of Irrigation District 003, with 95% of ejido plots irrigated with wastewater) (INEGI, 2006), coming from the Mezquital Valley (83.26% of agriculture is under annual and semi-permanent irrigation). This system results in very productive plots (corn: 15 tons per hectare versus 2.8 in SMM) but with considerable levels of contamination (SIAP, 2021; Domínguez-Narváez *et al*., 2023). The SMM community is better off than SBD in terms of certain healthy practices and a more favorable environment, or one less impacted by SSP. This is because rural populations commonly practice extensive and semi-organic backyard farming; they also tend to perceive a healthier environment compared to urban areas (Bautista-Santos *et al*. 2025); and the area is located in the upper part of the watershed and further from the SSP than the surrounding area. This geographical characteristic allows it to remain largely unaffected by its proximity to the Endho Dam and to be free of wastewater. Furthermore, it has plots of land irrigated with seasonal rainwater (41.9% of agriculture is rainfed) and remnants of natural vegetation, typical of the mesquite valley.

The perception of high to very high pollution levels among the population of SBD (74%) is a result of irrigating plots with wastewater and resulting airborne pollution, as well as the community's proximity to major SSP to the south (Cajuste *et al*. 1991). This assessment and analysis coincides with data from the

Government about the State of Hidalgo (2016), which places this community in one of the most polluted areas of the Valley of Mexico. It is important to note that both communities agree that the main risk factors for developing cancer are airborne pollutants (41%) and water (35%), which they attribute primarily to wastewater from the Endho Dam, the refinery, and the thermoelectric plant. The negative trend in the percentage of cancer cases across generations (Figure 3) is due to the fact that the incidence rate (new cases) of this disease increases with age (NCI, 2024). In SBD, the highest incidence of this disease occurs more frequently among women than men, which does not coincide with the national average: 48.5% and 51.5% in women and men, respectively (INEGI, 2024). This contrasts with SMM which is very similar to the national average; this is due to the number of breast and cervical cancer cases among maternal great-grandmothers and grandmothers. Generally speaking, the incidence of cervical, breast, lung, and other cancers is higher than in SMM. These last three cases are relevant, and their relationship with pollution may be due to the fact that, regarding breast cancer: Zhang *et al*. (2013) mention that this type of cancer is often associated with environmental risk factors. Wastewater pollution is a potential source of exposure to breast carcinogens, which reach the human body through airborne pollutants and contaminated crops. Similarly, organic solvents and other contaminants, often found in wastewater, have been detected in breast milk and various tissues, including breast and adipose tissue (Du Plessis *et al*. 2023). Lung cancer: this finding is perhaps the most relevant in this study (the leading cancer in the SBD community and 79% more prevalent compared to SMM). Pending further studies (activities in workshops or high-risk jobs, affected by airborne contaminants or sewage, etc.); this work corroborates the proposition that one of the main causes is particulate matter from industrial activity, very close to the area. Evidence of this relationship exists in the work of Clofent *et al*. (2021), regarding air pollution, and in the research conducted in the area by Guerrero and López (2019), on the effect of industrial gases (also known as greenhouse gases), a product of hydrocarbon combustion, primarily from pollution sources such as cement plants, the refinery and the thermoelectric industry. These authors also point out that 31% of lung cancer cases are attributable to environmental factors and that the Tula region has the highest probability of lung cancer risk in the entire Valley of Mexico region (Valle del Mezquital) due to these factors; as well as other types of cancer: there is a significant difference ($p > 0.05$) in this figure compared to SMM (lymphomas, leukemias, and tumors or neoplasms of the head), with a 79% higher rate. This research indicates that this is a consequence of wastewater pollutants and proximity to sources of suspended particulate matter emissions; thus, there is greater correlation between external agents than inherited genetic factors in the expression of various types of cancer. It is important to emphasize that, with the exception of cervical cancer the types of cancer related to pollution and most common in both communities (lung and breast) maintain the order of predominance reported by the WHO (WHO, 2024; Cajuste *et al*. 1991).

Cancer is a multifactorial disease, and these are associated with the development of its different manifestations. That is, beyond genetic predisposition, there are habits such as inadequate nutrition, being overweight or obese and lack of physical activity; the less healthy a person is, the greater the risk of neoplasms (SS, 2023). However, environmental factors also play a significant role in explaining the global burden of disease in regions with high pollution (Guerrero-López, 2022).

Regarding the perception of the interviewees (10% higher in SBD compared to SMM, on the very high to high scale) that environmental pollution levels are related to cancer, this concurs with other studies conducted in the area and in polluted locations (Du Plessis *et al*., 2023; Zhang *et al*., 2013; Guerrero-López, 2022). This assessment also correlates with family records on cancer incidence across four generations (59% higher in SBD compared to SMM) (Figure 3). Furthermore, this perception of environmental pollution in the communities and its relationship to various types of neoplasms should be considered in light of the fact that this perception leads to deductions and interpretations that the studied communities make collectively about their environment. In this way, an objective approach to environmental quality and its consequences—in this case, various manifestations of disease—is achieved.

Studies of land use, proximity to landfill, statistics and perceptions of respondents contribute to understanding the relationship between pollution and cancer in the study region. In this regard, the most polluted community is SBD, and here, the most common types of cancer related to pollution are lung and breast cancer. Regardless of conducting complementary studies on the relationship between cancer and pollution in the Valley of Mexico region (other case studies, genetic predisposition, diet, histological studies, case records due to greater access to health centers such as the ISSSTE or IMSS, etc.), the results from this study reveal a high incidence of pollution-related neoplasms across all comparative variables. Correspondingly several studies in the area have warned about levels of pollutants in the soil and water (arsenic, cadmium, lead, and pesticides) that are harmful to health. These are the result of wastewater and industrial activity, affecting crops, zooplankton, fish and consequently the human food chain. Similarly, concentrations of airborne particulate matter are linked to chronic degenerative respiratory diseases (Evangelou *et al*., 2016; Rubio-Franchini *et al*., 2016; Lesser *et al*., 2018).

Notably, the average family history of cancer in both case studies is higher than the overall population rate reported by the WHO (2024b), which states that 20% of the population develops cancer during their lifetime. This is based on the generational timeline of this study, with the rate being slightly higher (6% more) in the SBD community, indicated by the previously presented data. However, this information should be corroborated by other case studies using probabilistic sample analysis of adults, divided into age groups and cancer incidence rates. Other aspects should also be considered. For example, globally, the disease in all its forms has increased, which may be due to increased life expectancy and improved detection of these conditions, thanks to technological advances that facilitate diagnosis (WHO, 2024a). Furthermore, environmental factors are estimated to explain the global burden of cancer. In this regard, the Health Technology Assessment Agency (AETS) (2007) indicates that 19% of all cases are attributable to an unhealthy environment.

Regarding income, according to CONEVAL (2024), the SBD and SMM communities are above the income poverty line ($3,139.08, food and non-food basket): 205% SBD and 154% SMM; however, well below the threshold to escape poverty ($12,556.32), which is 51.5% and 38.6% less, respectively. According to INEGI (2020b), SBD, with a population of 7,999, is considered semi-rural compared to the rural community of SMM (2,337). Therefore, the SBD community has higher incomes due to better-paying jobs, which it diversifies with industrial and agricultural activities, typical of semi-rural communities (Bautista-Santos *et al*. 2025). In general, these incomes are consistent with studies conducted in other poor rural regions of the country, primarily in the Mazahua-Otomi area in the states of Mexico and Hidalgo, and in forest communities in Veracruz (Rodríguez *et al*. 2024; Bautista-Santos *et al*. 2025). This variable is important, as the link between high-cost diseases like cancer and poverty translates into inequity and exclusion suffered by this region of the Valley of Mexico, limiting access to quality healthcare services. In terms of cost-benefit (highly productive land irrigated with wastewater, with respect to its health effects); this would have to be assessed in the short and medium term.

This study can serve as a basis to increase understanding of the problem of pollution and its effects on public health in the area. In this regard, we recommend that various activities should be undertaken in the area to address this public health problem. In the short term, these should include public policies for prevention and early detection; primarily of breast and lung cancer. In the medium and long term, we recommend activities and projects complying with the declaration of the area as an Ecological Restoration Zone. For example, the construction or allocation of spaces in tertiary-level public health centers for cancer treatment. Additionally, economic studies should be conducted on the costs and fair compensation for both polluters and those affected. This last point is crucial not only because of the poverty affecting the population but also because of the threat to life itself: cancer caused by pollution. And in future research, the same methodology should be applied, recommending monitoring in more communities, both in the upper and lower basins of the Tula River. Environmental pollution in the Mezquital Valley worsened in the mid-1970s. In this timeline context and within this unfavorable environment, the curve of cancer case percentages should be studied with respect to generations, which would hypothetically tend towards zero. This is because the generations studied correspond to periods of lower pollution (the 1960s and 1970s) and higher pollution in the area (the last four decades), and thus, a higher incidence of cancer in its different forms at younger ages. Finally, this research suggests that prevention and early diagnosis offer promising and low-cost strategies for cancer control in the study region, especially preventive actions and early detection of lung and breast cancer.

CONCLUSIONS

In the study region, there is a trend and a perception among the population that wastewater and stationary sources of pollution cause various types of cancer. This trend can be analyzed by comparing two communities with different levels of pollution, employing records of various cancer cases over the last four generations, stationary sources of pollution, and people's perceptions of the link between pollution and cancer.

San Bartolomé Doxey (SBD) uses wastewater for its crops (83.26% of agricultural land) and is located closer to the main stationary sources of pollution (9.3 km on average). In Santa María Macuá (SMM), all crops are rain-fed and depend on freshwater sources; it is also further from these sources of pollution (approximately 22 km). This results in greater water, soil, and air pollution in SBD.

In both communities, there are significant differences in cancer incidence across four generations. The community with greater pollution has a 59% higher rate of family history of the disease. This excess (63%) is due to cases of cervical, lung, and breast cancer, as well as other cancers (lymphomas, leukemias, and tumors or neoplasms). The latter three could be related to sewage or wastewater pollution and certain suspended greenhouse gas particles.

Due to the proximity of the SBD community to polluting sources such as cement plants, thermoelectric plants and refineries, these environmental factors may have greater impact on lung cancer.

The respondents' perceptions of the most frequent types of cancer and the degree of pollution corroborate the results regarding both land use and statistics: the most affected community is SBD, and within it, the most common types of cancer, for which there is a history of linking them to pollution, are lung and breast cancer. This order of importance is similar to that reported by national and international organizations.

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