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Epidemiological and spatial analysis of breast cancer mortality and survival among women in San Luis Potosi, Mexico 2009-2019

Carlos Daniel Coronado-Ruis,[1] Enrique Ibarra-Zapata,[2] Darío Gaytán-Hernández,[1] Sergio Zarazúa-Guzmán,[3] Thuluz Meza-Menchaca,[4] Marisol Gallegos-García,[5] Omar Medina-de la Cruz,[1] Verónica Gallegos-García[1]

[1]Faculty of Nursing and Nutrition, Autonomous University of San Luis Potosí; [2]Faculty of Agronomy and Veterinary Medicine, Autonomous University of San Luis Potosí; [3]Faculty of Chemical Sciences, Autonomous University of San Luis Potosí; [4]Laboratory of Research in Medical-Biological Sciences, Faculty of Medicine, Veracruzana University, Médicos & Odontólogos, Virginia Cordero de Murillo Vidal, Xalapa; [5]Faculty of Engineering, Autonomous University of San Luis Potosí, San Luis Potosí, Mexico

Abstract

This study investigated variations in breast cancer mortality among women in San Luis Potosí, Mexico using an epidemiological-spatial approach covering the period 2009–2019. Additionally, global and specific survival and its associations with clinical stage, age at diagnosis, marginalization index, recurrence and arsenic concentration in water were evaluated. We conducted a retrospective ecological, study involving1, 626 confirmed breast cancer cases and 264 related deaths registered at a public hospital. Survival analysis was performed using the Kaplan-Meier method and Log-Rank tests. Spatial distribution patterns of municipal average mortality were assessed using Moran's I and visualized in ArcMap 10.1. At the state-level the mean age at diagnosis among deceased patients was 53.49 years, with 84% presenting at advanced stages (IIB–IV). A progressively increased mortality, particularly in Health Jurisdiction IV and the municipality of Cerro de San Pedro, was observed, with peaks in 2016. The 5-year global survival rate was 83.78%. Factors significantly associated with reduced survival included advanced stage, older age, higher marginalization index and recurrence. Although arsenic exposure was not statistically significant, patients exposed to levels exceeding 0.025 mg/L exhibited longer survival times. The integration of spatial epidemiology with survival analysis underscored critical geographic and socio-demographic disparities and offer valuable insights for targeted healthcare planning and resource allocation, particularly in high-priority regions.

Key words: Public health, spatial distribution patterns, women's health diseases, cancer, prevention, Mexico.

Correspondence: Verónica Gallegos-García, Avenida Niño Artillero no. 130, Zona Universitaria, CP 78240, San Luis Potosí, San Luis Potosí, Mexico. Tel: +52.444.8262300 Ext.: 5027. E-mail: veronica.gallegos@uaslp.mx

Introduction

Breast Cancer (BC) is a disease characterized by uncontrolled division of cells in the breast, although different subtypes exist depending on the specific tissue involved. According to the Centers for Disease Control and Prevention (CDC) in the United States, BC may arise in the lobules, ducts, or connective tissues of the breast (CDC, 2024). This type of cancer is the most common cancer among women, primarily affecting those aged 40 and older, while in men it accounts for only 0.5-1% of all cases. According to estimates from the World Health Organization (WHO), in 2022, BC was diagnosed in 2.3 million women worldwide, resulting in 670,000 deaths. It is important to note that most of these deaths occurred in countries with a low Human Development Index (WHO, 2024).

According to the National Population Council (CONAPO) in Mexico, a shift in the country's epidemiological profile has been ongoing since the 1980s. This transition is marked by a decline in communicable diseases and a rise in the morbidity and mortality associated with non-communicable chronic diseases (CONAPO, 1999). In this context, the Ministry of Health, through its National Center for Gender Equity and Reproductive Health in Mexico (CNEGSR), reported that in 2015, 291,637 deaths among women were registered nationwide, with 13.9% attributed to malignant tumours. Among tumour-related deaths, BC ranked first, accounting for 15.4%, followed by cervical cancer (9.9%) and ovarian cancer (5.9%) (CNEGSR, 2015). At the state level, Mexico's autonomous public agency responsible for collecting, analyzing and disseminating official data on the country's economy, population and geography (INEGI) recorded for San Luis Potosí 167 deaths due to BC in 2023 among women (INEGI, 2023).

Several factors can influence BC mortality and, consequently, survival rates. In this regard, mortality and survival are closely, inversely related. The factors affecting BC survival are often referred to as prognostic factors. González-Ortega *et al.* (2011) identified several such factors, including age at diagnosis, axillary involvement, tumour size and lymphatic/and vascular invasion, with the latter three directly related to the stage of the cancer. In

addition, recurrence (Rodríguez-Sarria *et al.*, 2018; Heredia-Caballero *et al.*, 2018) and poverty (WHO, 2024) are also associated with poor prognosis. Beyond the aforementioned factors, arsenic exposure has been suggested to a contribute to higher cancer mortality, even at low to moderate exposure levels (García-Esquinas *et al.*, 2013). Furthermore, arsenic concentration in water has been linked to increased risk of various other cancers and also chronic diseases (Chiou *et al.*, 1995; Kuo *et al.*, 2022). This is particularly relevant in the state of San Luis Potosí, where certain geographic regions show notable arsenic contamination, caused by both natural geological processes and anthropogenic activities such as mining (Armienta & Segovia, 2008).

BC is considered a major public health issue, new strategies, approaches, and technologies have been sought to support strategic decision-making including Health Geography (HG), an interdisciplinary subfield of geography focusing on how place and environment influence human health. Although HG has traditionally been applied in the epidemiology of infectious diseases, it is now increasingly used in the study of non-communicable diseases such as cancer (UNC, 2015). HG aims to provide a spatial perspective on health issues to better understand the distribution of health and disease (Barcellos *et al.*, 2018). This information constitutes a valuable resource for the planning and evaluation of healthcare services and for the design of effective prevention, diagnosis, and treatment policies (Díaz *et al.*, 2010). More recently, HG has been applied to the analysis of BC patterns. The Nacional Universidad de Córdoba (UNC) in Argentina conducted a study in Córdoba Province based on data from the Directorate of Statistics and Censuses, as well as mortality records from the National Directorate of Health Statistics and Information in Argentina, to develop a statistical modelling framework for BC and prostate cancer. One of its key findings was that BC follows a non-random spatial distribution pattern (UNC, 2015). In Ecuador, another HG-based BC study identified clusters of BC mortality across different provinces, which revealed a non-homogeneous distribution and differences between urban and rural settings. Specifically, the study highlighted the lack of specialized literature available for comparative analysis and emphasized the need to examine additional environmental variables to better understand the BC phenomenon. The authors concluded that data gathered through a HG perspective is essential for the development and implementation of effective control strategies (Jaramillo *et al.*, 2020).

The objective of this study was to analyze spatial variations in BC mortality among uninsured women in San Luis Potosí from 2009 to 2019 using an epidemiological-spatial approach. Additionally, 5- and 10-year overall survival rates were estimated and their association with clinical stage, age at diagnosis, marginalization index (MI), recurrence and arsenic concentration in water (As-W) was assessed.

Materials and Methods

Study design

This was a quantitative study with an ecological, cross-sectional, and retrospective epidemiological design. The sample consisted of all records of newly diagnosed BC cases and related deaths among uninsured women in the state of San Luis Potosí, Mexico.

The inclusion criteria were uninsured women without social security coverage, who had been diagnosed with BC between 2009 and 2019, treated at the state's public referral centre for the uninsured population and registered in the hospital database. The exclusion criteria included the records of patients whose residence was outside the state of San Luis Potosí, or whose diagnosis or death occurred outside the study period. Records of patients who could not be georeferenced, lacked date of birth information, or were duplicate were eliminated.

Unit of analysis

The mortality analysis was conducted at multiple geographic scales: state, Health Jurisdiction (HJ) and municipality. The State of San Luis Potosí is composed of 58 municipalities organized into seven HJs, in which the Secretariat of Health (SSa), is the federal cabinet-level authority responsible for health services, policy and regulations (SSa, 2022; INEGI, 2025): i) San Luis Potosí, ii) Matehuala, iii) Soledad de Graciano Sánchez, iv) Rioverde, v) Ciudad Valles, vi) Tamazunchale and vii) Tancanhuitz.

Data collection

The initial dataset was obtained from the state's public referral hospital and consisted of an Excel file containing 1,925 records of BC cases from 2009 to 2019. After applying the inclusion and exclusion criteria, the final sample size was 1,626 records. Based on the guidelines of the American Cancer Society (ASC, 2021), the dataset included the following variables: case ID, age, date of diagnosis, BC stage at diagnosis, state, municipality and date of death. However, in some cases, the stage was recorded as recurrent, persistent or unclassifiable.

Descriptive statistics and mortality rates

Out of the 1,626 records contained in the database only 273 indicated patient death. However, five records lacked information on the year of death, and four deaths occurred in 2020. These nine cases were excluded from mortality analyses, resulting in 264 records used for this component. Importantly, the entire sample (n = 1,626) was included in the survival analysis, while only the 264 death records were used to calculate descriptive statistics and mortality rates.

The mortality dataset was filtered in Excel to generate separate worksheets corresponding to BC cases at the state, HJ and municipal levels. Each dataset was subsequently analyzed using PAWS statistics, version 18, applying the 'frequencies' tool to obtain descriptive metrics: frequency, minimum, maximum, mean, median and Standard Deviation (SD) for age. For cancer stage, only frequency and percentage were computed. To estimate the BC mortality rate, population data were obtained for women aged 20 years and older in each municipality of San Luis Potosí. Sources included the 2005 Population and Housing Count and the 2010 and 2020 Censuses from INEGI. For years without census data, municipal-level population estimates were derived using linear interpolation in Excel, based on the following formula.

$$y = ya + (x - xa)\frac{(yb-ya)}{(xb-xa)} \quad \text{Eq. 1}$$

where y is the estimated population; ya the initial population; yb the final population; x the year estimated; xa the initial year; and xb the final year.

The population for non-census years was estimated using the following linear interpolation formula.

The resulting population estimates were adjusted by the percentage of the population uninsured, as reported by the National Council for the Evaluation of Social Development Policy in its Poverty and Evaluation Report for the state of San Luis Potosí up

to the year 2020 (CONAPO, 2020). This adjustment allowed for the calculation of mortality rates specific to the uninsured population, thereby avoiding the dilution of rates across populations with and without with sure and uninsured. Once the number of women aged 20 and over uninsured had been estimated for each level of analysis (state, HJ and municipality), the BC mortality rates were calculated using the number of deaths within the study period, applying the following formula for each year and scale:

$$\text{Mortality rate} = \frac{\text{(Number of deaths in the study group)}}{\text{(Population of women aged 20 and over per year)}} \times 100{,}000 \quad \text{Eq. 2}$$

Additionally, to facilitate municipal-level analysis, the average mortality rate was calculated for each municipality across the study period.

Spatial modelling of breast cancer mortality

Modelling of the average BC mortality rates and their spatial distribution was conducted using ArcMap, version 10.1, based on the World Geodetic System (WGS) 1984 coordinate system. The territorial boundaries of the state of San Luis Potosí and its 58 municipalities were obtained from INEGI in Shape File format and the political division maps of Mexico at the state and municipal levels (scale 1:250,000) were extracted as polygonal shapefiles. A cartographic reconstruction of the seven HJs in San Luis Potosí was then developed, using data from the Unique Key Catalog of Health Establishments provided by the General Directorate of Health Information of the Ministry of Health. This process involved overlaying state and municipal boundaries to generate the HJ divisions.

A spatial database was created from an Excel file, which was later exported into ArcMap and saved as a shapefile. This database contained municipal-level attributes, including average BC mortality rates and geographic coordinates of each municipal seat. To perform geographic modelling of average mortality rates, the Inverse Distance Weighting (IDW) method (Esri) was applied. The output cell size was set to 10%, and five classes were used to represent mortality rates. These classes were determined using the Geometrical Interval Classification method (Esri), selected due to the high variability of the data and its ability to provide a more accurate representation of the variable.

For the geostatistical analysis of BC mortality, we applied Global Moran's *I* to the average BC mortality rates of each municipality, assigning the geographic coordinates of their corresponding municipal centres. Moreover, we analyzed the same data using the hotspot analysis test (Getis–Ord Gi*) to identify local geographic areas with similar low values (coldspots) or similar high values (hotspots), which were statistically significant based on the Getis–Ord Gi Z-score.

Survival analysis

BC survival was analyzed in relation to the following variables: clinical stage, age at diagnosis, MI, recurrence and As-W. However, for the environmental variables, MI and As-W specific values were not available in the patient records provided by the public referral hospital. Therefore, the municipal-level MIs were obtained from data provided by the CONAPO for the years 2005, 2010 and 2015. From these data, an average MI value was calculated and used to construct a Spatial Database (SDB) by linking the mean MI value to the geographic coordinates of each municipal seat. Arsenic concentration data were sourced from the National Water Commission (CONAGUA) for the period 2012 to 2020, covering the states of Guanajuato, Hidalgo, Nuevo León, Querétaro, San Luis Potosí, Tamaulipas, Veracruz and Zacatecas. A total of 1,582 georeferenced sampling sites were included, encompassing lentic, lotic, subterranean and coastal water bodies. The arsenic concentration at each site was averaged and reported as mean As-W concentration in mg/L, forming the basis of a second SDB.

Modelling of the MI and As-W variables was developed using the methodology applied to the average BC mortality. Subsequently, through a geometric overlay analysis, the values of each variable (MI and As-W) were extracted for each BC case based on its coordinates. This was performed using the 'Extract Multi Values to Points' tool. Subsequently, the variables were organized for analysis. The variable *Stage at Diagnosis* was subdivided into eight categories (Table 1). For the variable *Age at Diagnosis*, the age groups defined by INEGI in its national mortality statistics were applied (INEGI, 2024). The MIs were categorized into five levels: very low (−1.52944 to −1.15143), low (−1.15143 to −0.39539), medium (−0.39539 to −0.01738), high (−0.01738 to 0.73866) and very high (0.73866 to 2.2507). Recurrence was treated as a dichotomous variable and for As-W, the classification followed the limits established by the Mexican standard NOM-127-SSA1-2021 on Water for Human Use and Consumption: Permissible Quality Limits as given in the Mexican Official Government Gazette (DOF) (2022).

The Kaplan–Meier survival curves (IBM, 2026) were used to graphically represent global survival and survival across categories of each variable. The median survival time, expressed in months, was also reported. In addition, the Log-Rank test (Mantel–Cox) (Hazra & Gogtay, 2017) was applied to the dataset. This non-parametric test identifies differences in survival across two or more categories of a variable (Terán-Figueroa *et al.,* 2024), using the chi-square statistic and corresponding *p*-value to assess significance.

Table 1. Overview of the different clinical stages of breast cancer.

Stage	Description
In situ	Cancer growth contained within the milk ducts without spread into the surrounding tissues
I (IA & IB)	Early-stage, small tumour without or with tiny lymph node involvement
IIA	Early, locally advanced cancer of small size, either with minimal lymph node involvement or larger size (2-5 cm) without any lymph node involvement
IIB	Early, locally advanced cancer, either with larger size (2-5 cm) and minimal lymph node involvement or larger (>5 cm) without lymph node involvement
IIIA	Locally advanced tumour of larger size with lymph node involvement
IIIB	Local spread to chest wall and/or skin, possibly affecting several lymph nodes
IIIC	Any size tumour involving lymph nodes under or above the collarbone
IV	Metastatic cancer

As with descriptive statistics, analyses were performed using PAWS Statistics software.

Results

Age and stage of BC at diagnosis

Among all recorded BC-related deaths during the study period (n = 264), the age at diagnosis ranged from 25 to 93 years (range = 68 years), with a mean of 53.5 years, median of 52.0 years, and SD of 13.85 years. The most frequently reported cancer stage among deceased women at the state level was stage IIIA, accounting for 20.1% of cases, while the least commonly diagnosed stage was stage I, with only 0.4%. Notably, 84% of the women who died from BC were diagnosed at advanced stages (IIB to IV). In contrast, only 6.8% were diagnosed at early stages (I to IIA). The remaining cases were categorized as recurrent or lacked specification of the recurrence stage. However, the distribution of both age at diagnosis and cancer stage varied across HJ, as shown in Table 2. It is worth noting that Health Jurisdiction IV (Rioverde) reported the highest mean and median age at diagnosis for BC in the state of San Luis Potosí, with 57.0 years and 59.0 years, respectively. The majority of cases in this jurisdiction were diagnosed at stage IIIB (26.5%).

Spatiotemporal analysis of breast cancer mortality

BC mortality rates in the state of San Luis Potosí between 2010 and 2019 are shown in Figure 1. It can be observed that the mortality rate per 100,000 women aged 20 years and older uninsured showed an upward trend throughout the period. The behaviour of the mortality rate remained relatively stable from 2012 to 2019, fluctuating between 6.0 and 7.1 deaths per 100,000 women. The highest mortality rate was recorded in 2016, with 9.2 deaths per 100,000 women aged 20 and over uninsured the peak rate during the entire study period. At the jurisdictional level, HJ-IV (Rioverde) registered the highest breast cancer mortality rate per 100,000 women aged ≥20 years and remaining uninsured throughout the decade analyzed, reaching 23.2 deaths in 2017. Additionally, this jurisdiction showed a sustained increase in BC-related deaths from 2016 (18.5) to 2018 (19.6) a trend higher than that of the other jurisdictions. The second highest overall mortality was observed in HJ-III (Soledad de Graciano Sánchez), with a peak rate of 14.7 deaths per 100,000 women in 2016.In contrast, HJ-VI (Tamazunchale) recorded the lowest breast cancer mortality rates per 100,000 women aged ≥20 years and remaining uninsured during the study period (Figure 2).

The BC mortality rate per 100,000 women aged ≥20 years and without insurance coverage was averaged across the ten-year study period at the municipal level. The results are presented in Figure 3. During this period, the municipality with the highest average BC mortality rate was Cerro de San Pedro, with 134.1 deaths, followed by Villa de la Paz (123.3), Villa Juárez (113.3), San Nicolás Tolentino (104.2), and Lagunillas (103.8) all reported per 100,000 women aged ≥20 years and without social security. In contrast, the municipalities of Armadillo de los Infante, Axtla de Terrazas, Real de Catorce, El Naranjo, Huehuetlán, San Antonio, Santo Domingo, Tampacán, Tampamolón Corona, Tierra Nueva, Vanegas, Villa de Guadalupe and Villa Hidalgo recorded no BC-related deaths from 2010 to 2019 and therefore did not generate mortality rate values for this period (Figure 3).

Regarding the spatial variation in average BC mortality rates per 100,000 women in the state aged ≥20 years and remaining uninsured (Figure 4), a distinct geographic pattern emerged, characterized by a high-mortality corridor (40.40-72.01) crossing HJs I, II, III and IV. Additionally, isolated high-mortality zones were identified outside this corridor, located in the municipalities of Venado (HJ-II), Ahualulco (HJ-III), Matehuala (HJ-III), Cedral (HJ-III), Tancanhuitz (HJ-VII) and Tanquián de Escobedo (HJ VII). Within the high-mortality corridor (40.4-72.0), six geographic hotspots were identified with very high mortality rates (72.0-134.1). These areas include the municipality of Cerro de San Pedro (HJ-III), bordering Soledad de Graciano Sánchez (HJ-I); San Nicolás Tolentino, Cerritos and Villa Juárez, which are located in the western part of HJ-IV; Alaquines, in the eastern portion of HJ-IV; and Lagunillas and Santa Catarina, which are situated in the southern region of the same jurisdiction. Additionally, in the northern part of the state, the municipality of Villa de la Paz (HJ-II) also stood out for having very high mortality rates.

Despite these spatial patterns, the result of the Moran's *I* was 0.001280, with a Z-score of 0.357277 and a *p*-value of 0.720884. Therefore, the spatial distribution of BC mortality rates does not appear to be significantly different from random (Figure 4). However, this test evaluates spatial dependence under the assumption of homogeneity across the entire study area and may therefore be insensitive to localized patterns. In this context, the hotspot

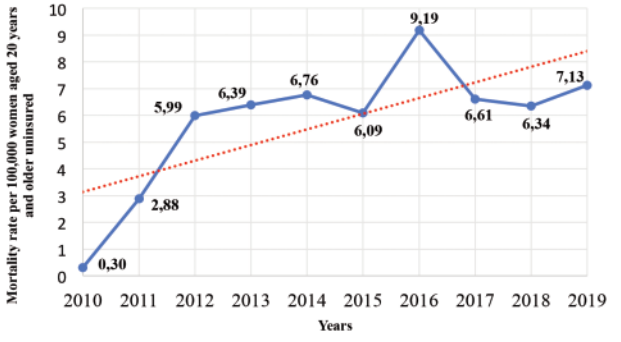


Figure 1. Breast cancer mortality in the state of San Luis Potosí 2010-2019.

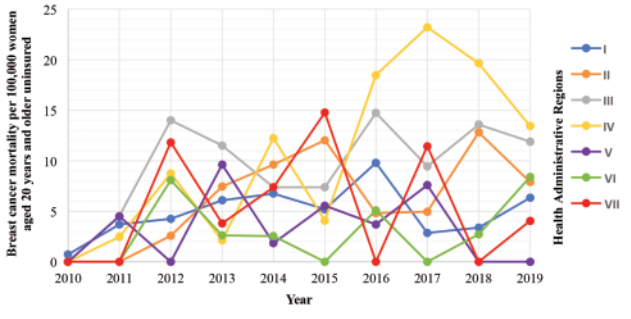


Figure 2. Breast cancer mortality by health jurisdiction I-VII in the state of San Luis Potosí 2010-2019.

analysis allowed the identification of local spatial clusters. Figure 5 shows statistically significant hotspots in HJ-IV (Rioverde). More specifically, we observed a cluster of municipalities with high mortality rates in the southern part of this jurisdiction: San Nicolás Tolentino, Cárdenas, San Ciro de Acosta and Lagunillas (p=0.1), as well as Rayón (p=0.05) and Rioverde (p=0.01). This suggests that spatial heterogeneity at the local scale that is not identified by the global analysis (see Figure 5).

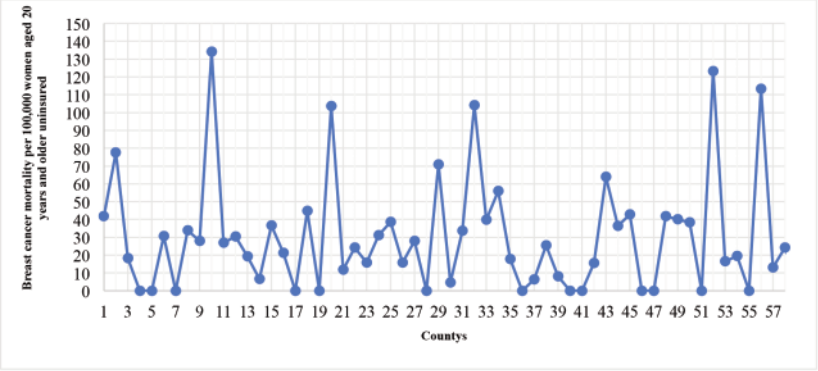
Survival analysis

According to the Kaplan–Meier survival analysis, the overall 5-year survival rate for the study sample was 83.8%, while the 10-year survival rate decreased slightly to 82.8%. The mean survival time among women with BC was 111.8 months (95% CI: 109.5-114.0). Figure 6 presents both the overall survival curve and the stratified survival curves for each variable analyzed using the Kaplan–Meier method.

Survival outcomes based on clinical stage showed the highest survival in women diagnosed with *in situ* disease, followed by stages I, IIA, IIB, IIIA, IIIB, IIIC and IV, in descending order. A statistically significant difference in survival ($p \leq 0.05$) was observed between the following stage comparisons: IIB vs. I and IIA; IIIA vs. I and IIA; IIIB vs. *In situ*, I and IIA; IIIC vs. *In situ*, I, IIA, IIB and IIIA; IV vs. all other stages (*In situ* to IIIC). Notably, stage IV patients exhibited a highly significant reduction in survival compared to all other clinical stages (p=0.000), as shown in (see *Supplementary materials, Table S1*).

Regarding the variable age at diagnosis, survival was highest among women diagnosed with BC in the 15-24-year age group, followed by the 55-64, 35-44, 45-54, ≥65 years finally the 25-34-year groups (Figure 6). A statistically significant difference in survival ($p \leq 0.05$) was found between the following age groups: 25-34 years vs. 45-54 years and 25-34 years vs. 55-64 years (*Supplementary materials, Table S1*). For the variables 'clinical stage' and 'age at diagnosis', it was not possible to calculate descriptive statistics for mean survival time (in months) because all these cases were censored.

With respect to the MI, an inverse relationship was observed: as MI increased, survival decreased. The highest average survival time was recorded in the very low MI group (114.9 months), followed by low (113.6 months), medium (110.3 months), high (105.4 months) and very high (107.0 months) groups (Figure 6). A statistically significant difference in survival was found between the categories: high vs. very low and high vs. low MI



							San Martín		Tampamolón		Villa de
1	Ahualulco	11	Charcas	21	Matehuala	31	Chalchicuautla	41	Corona	51	Guadalupe
			Ciudad del				San Nicolás				Villa de la
2	Alaquines	12	Maíz	22	Matlapa	32	Tolentino	42	Tamuín	52	Paz
			Ciudad				San Vicente				Villa de
3	Aquismón	13	Fernández	23	Mexquitic	33	Tancuayalab	43	Tancanhuitz	53	Ramos
	Armadillo										
	de los		Ciudad								Villa de
4	Infante	14	Valles	24	Moctezuma	34	Santa Catarina	44	Tanlajás	54	Reyes
	Axtla de						Santa María				Villa de
5	Terrazas	15	Coxcatlán	25	Rayón	35	Del Rio	45	Tanquián	55	Hidalgo
							Santo				Villa
6	Cárdenas	16	Ébano	26	Rioverde	36	Domingo	46	Tierra Nueva	56	Juárez
	Real de										
7	Catorce	17	El Naranjo	27	Salinas	37	Soledad	47	Vanegas	57	Xilitla
					San						
8	Cedral	18	Guadalcázar	28	Antonio	38	Tamasopo	48	Venado	58	Zaragoza

Figure 3. Breast cancer mortality by health jurisdiction I-VII in the state of San Luis Potosí 2010-2019.

(*Supplementary materials, Table S1*). Recurrence significantly affected BC survival: women who experienced recurrence had a markedly lower average survival compared to those who did not (46.5 *vs.* 113.2 months; $p = 0.000$), as illustrated in Figure 6.

Finally, while the variable 'As-W, mg/L' was not statistically significant according to the Log-Rank (Mantel-Cox) test, the Kaplan-Meier curves revealed that women exposed to As-W concentrations greater than 0.025 mg/L had a longer average survival time compared to those exposed to lower or permissible levels according to the NOM-127-SSA1-2021 standard. On the other hand, the map of the As-W distribution (mg/L) in the state shows the estimated As-W concentration during the study period (see Figure 7).

Discussion

To date, there are no more reliable evaluations of BC mortality and survival for populations with and without social security in the state. Nevertheless, the present study provides valuable data to describe the phenomenon under investigation, through an epidemiological-spatial analysis of BC mortality and survival among uninsured women in San Luis Potosi during the 2009-2019 period, as discussed below. Importantly, however, these results are strictly generalizable only to women without social security coverage in San Luis Potosi. The BC mortality rate among uninsured women in San Luis Potosi increased approximately 24-fold between 2010 and 2019. This positive trend in mortality rates is consistent with observations from other studies conducted in the Latin America and Caribbean region (Azamjah *et al.*, 2019), as well as in Mexico. In fact, a BC mortality study conducted in Jalisco between 2010 and 2017 revealed a similar trend, reporting the lowest mortality rate at 10.73 deaths per 100,000 women aged ≥20 years in 2010, which steadily increased until peaking in 2016 at 13.45 deaths, before declining slightly to 13.05 deaths in 2017 (Ramos-Herrera *et al.*, 2020).

State-wide fluctuations in breast cancer mortality rates may reflect variations in the proportion of the uninsured population affiliated with Seguro Popular (SP), which was a prerequisite for receiving diagnostic, treatment and follow-up services at the state referral hospital. Notably, both the mortality rate and the percentage of SP affiliates exhibited similar fluctuations over time. In Mexico, SP provided healthcare services to the uninsured population between 2004 and 2019. In San Luis Potosi, SP affiliation steadily increased from 27.9% in 2008 to 55.0% in 2014, followed by a gradual decline to 49.2% by 2018 (CONAPO, 2020). At the state level, the mean age at diagnosis among women who died from BC was 53.5 years, and the most frequent clinical stage at diagnosis was stage IIIA, with 84% of women diagnosed between stages IIB and IV. According to the NOM-041-SSA2-2011 guidelines for the prevention, diagnosis, treatment, control and epidemiological surveillance of breast cancer in Mexico, Appendix F classifies BC as intermediate or high risk when the tumor size exceeds 2 cm and there is axillary lymph node metastasis (DOF, 2011). This description corresponds to stages IIB to IV. Considering this, it can be concluded that at the state level, the majority of uninsured women who died from BC were diagnosed at an advanced stage.

Tatalovich *et al.* (2015) suggest that a higher proportion of late-stage BC diagnoses is associated with lower availability of mammography units. This point is critical, given that survival in breast cancer depends largely on early detection (López-Carrillo *et al.*, 2009). Furthermore, patients diagnosed at intermediate or high-risk stages require different therapeutic approaches compared to those diagnosed at low-risk stages (DOF, 2011). In this regard, several authors (Tatalovich *et al.*, 2015; Reyna-Sevilla *et al.*, 2020) propose using late-stage diagnosis as a predictor of BC mortality,

Table 2. Descriptive statistics of age and stage at diagnosis of breast cancer in uninsured women by health jurisdiction 2010–2019.

Age (years) HJ	Number	Minimum	Maximum	Mean	Median	SD
I	99	29	85	53.0	51	13.6
II	25	29	80	52.4	52	12.6
III	49	32	89	53.3	51	14.1
IV	49	26	93	57.0	59	15.7
V	17	25	65	49.2	52	11.4
VI	11	30	85	49.5	48	15.9
VII	14	35	74	55.4	54	10.7
State	264	25	93	53.5	52	13.9

HJ, health jurisdiction; SD, standard deviation.

Stage HJ	I		IIA		IIB		IIIA		IIIB		IIIC		IV		Recur-rence		Total
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	
I	-	-	7	7.1	18	18.2	18	18.2	17	17.2	11	11.1	14	14.1	14	14.1	99
II	-	-	2	8.0	7	28.0	8	32.0	3	12.0	-	-	4	16.0	1	4.0	25
III	-	-	5	10.2	9	18.4	8	16.3	4	8.2	5	10.2	12	24.5	6	12.2	49
IV	-	-	-	-	8	16.3	12	24.5	13	26.5	5	10.2	9	18.4	2	4.1	49
V	1	5.9	1	5.9	3	17.7	1	5.9	-	-	3	17.7	8	47.1	-	-	17
VI	-	-	-	-	3	27.3	3	27.3	1	9.1	1	9.1	3	27.3	-	-	11
VII	-	-	2	14.3	2	14.3	3	21.4	2	14.3	2	14.3	2	14.3	1	7.1	14
State	1	0.4	17	6.4	50	18.9	53	20.1	40	15.2	27	10.2	52	19.7	24	9.1	264

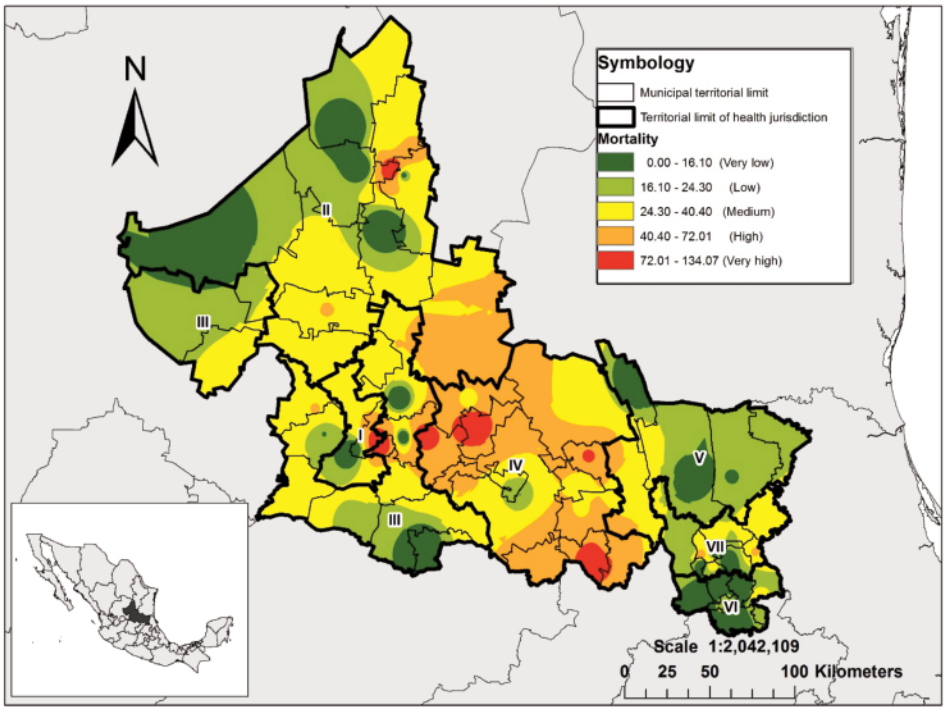


Figure 4. Geographic distribution across Health Jurisdictions I-VII of the average breast cancer mortality rate per 100,000 uninsured women aged 20 years and older in San Luis Potosí State 2010-2019.

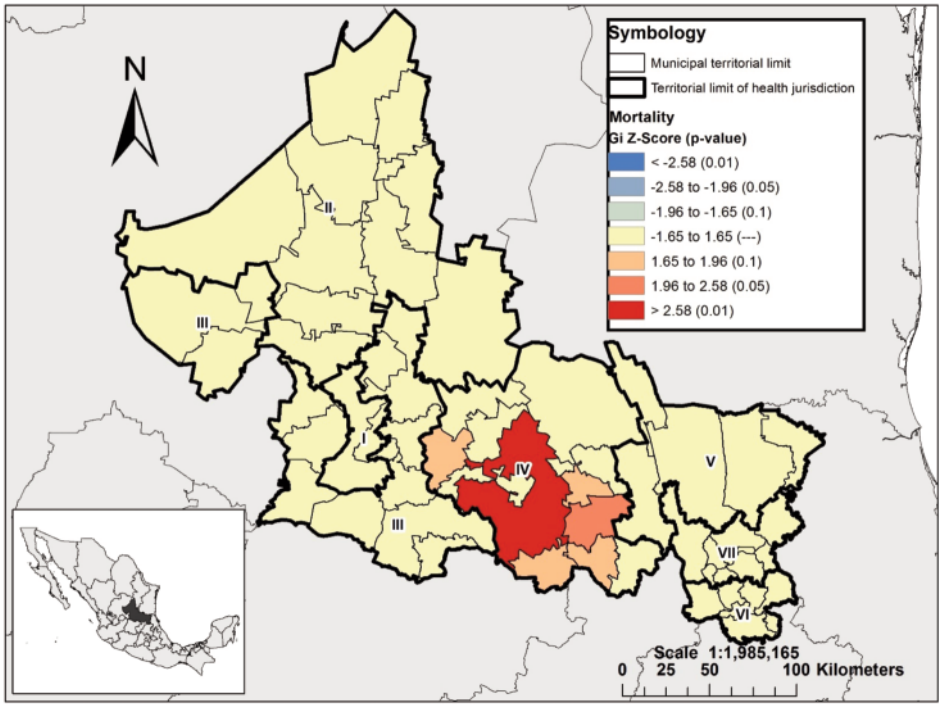


Figure 5. Hotspot distribution across Health Jurisdictions I-VII of the average breast cancer mortality rate in San Luis Potosí State 2010-2019.

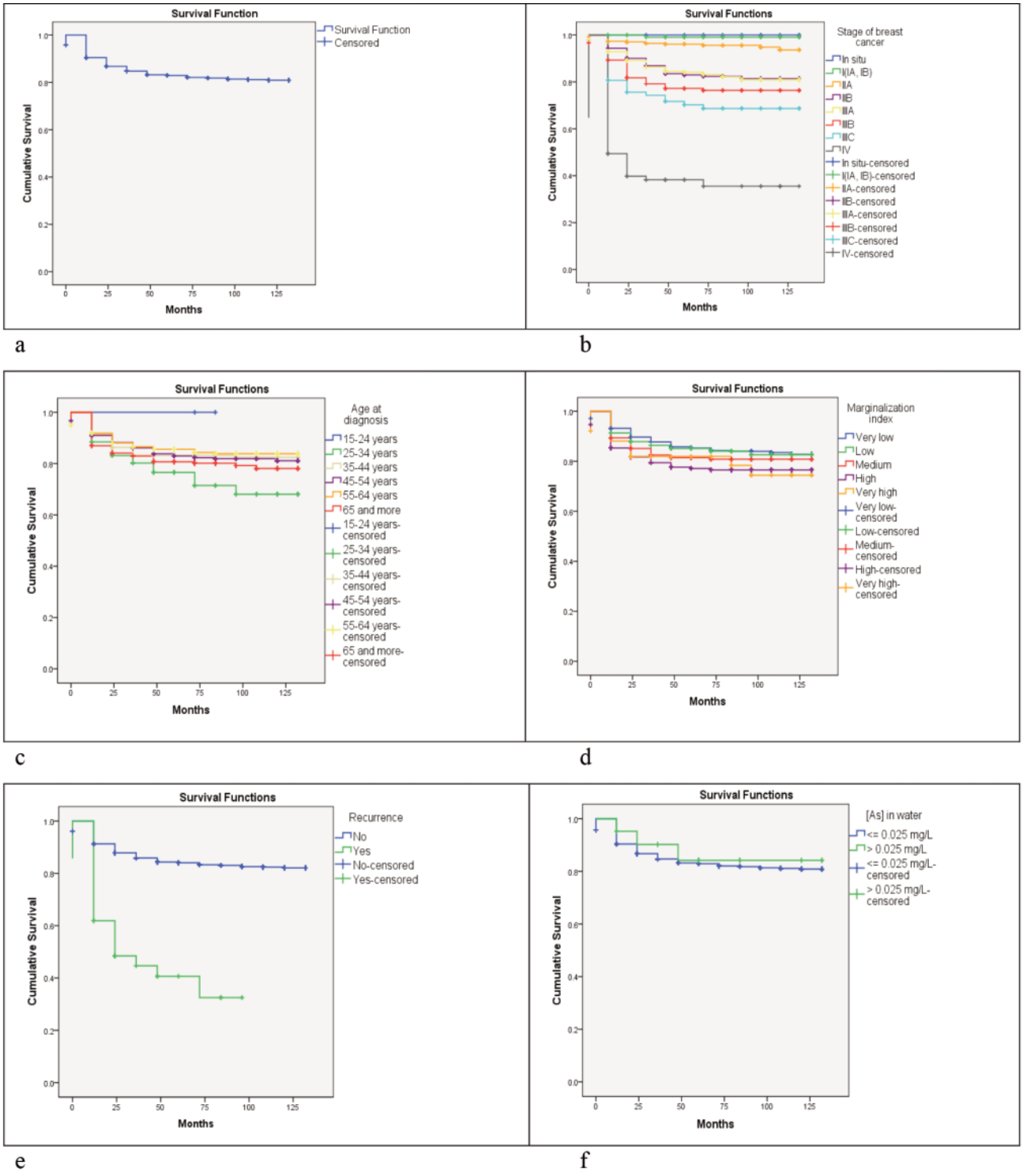


Figure 6. Global survival of women with breast cancer and stratified according to the different study variables. **a**) global survival; **b**) stage of breast cancer diagnosis; **c**) age at diagnosis; **d**) marginalization; **e**) recurrence; **f**) arsenic concentration in water (mg/L).

aiming to identify geographic areas for targeted health interventions. In our study, HJ-IV (Rioverde) recorded the highest BC mortality rate among uninsured women aged 20 years and older across the study period. Moreover, this jurisdiction not only had a high proportion of diagnoses at intermediate and high-risk stages, but also reported the highest mean and median ages at diagnosis 57.0 years and 59.0 years, respectively. These findings suggest that programmes aimed at reducing BC mortality should primarily focus on geographic areas where both age at diagnosis and clinical stage are late, such as in Health Jurisdiction IV (Rioverde) (Reyna-Sevilla *et al.*, 2020). Importantly, this does not imply neglecting other regions within the state, but rather prioritize resources toward areas most affected by BC, while maintaining an intercultural perspective. Programmes designed to decrease mortality in these high-risk areas should strengthen knowledge and awareness about clinical breast examination, breast self-examination and mammography among the population (López-Carrillo *et al.*, 2009), as low awareness of BC detection methods has been associated with higher mortality rates (Roche *et al.*, 2002). These initiatives should be complemented by an increase in the availability of mammography units and by ensuring timely treatment access (Tatalovich *et al.*, 2015), while also addressing cultural beliefs and perceptions about mammography, which may serve as barriers to participation in screening programs (Engelman *et al.*, 2012). Special emphasis should be placed on health centres located in regions with the highest mortality rates or where late-stage diagnoses are most common.

Regarding the survival analysis, the Kaplan-Meier method showed a 5-year survival rate of 83. 8% and a 10-year survival rate of 82.8%, with an overall mean survival time of 111.8 months (95% CI: 109.5-114.0). The 5-year survival rate observed in this study is similar to previous reports from other studies conducted in Mexico (Maffuz-Aziz *et al.*, 2016). However, both the 10-year survival rate and the mean survival time were lower than those reported in high-income countries such as South Korea and Spain, where survival rates of 84.8% (Park *et al.*, 2017) and mean survival times of 119.9 months (Ocón-Hernández *et al.*, 2010), respectively, have been documented.

With regard to survival outcomes across clinical stage, age and MI, the findings of this study were consistent with previous national research on breast cancer survival among the uninsured population. For example, the study based on data from the National Commission for Social Protection in Health, which managed the SP programme, and included 56,847 BC cases between 2007 and 2016 (Unger-Saldaña *et al.*, 2023). Contrary to expectations, the groups in our study with the lowest survival rates were women diagnosed between 25-34 years of age, followed by those ≥65 years. The lower survival observed among younger women may be attributed to the fact that BC tends to have a more aggressive clinical course in this group, leading to a worse prognosis compared to that for older women (Azim *et al.*, 2014). Alternatively, it may be explained by diagnostic delays in young women (Jassem *et al.*, 2014), largely due to a lower clinical suspicion of breast cancer at the primary care level, which can result in longer diagnostic intervals for younger women compared to older women (Unger-Saldaña *et al.*, 2019). Meanwhile, women aged ≥65 years may experience delayed diagnosis due to the presence of comorbidities and barriers to healthcare access. Additionally, women in this age group often receive suboptimal treatment, further worsening their prognosis (Lodi *et al.*, 2017).

Regarding marginalization, our findings are similar to those of the national study (Unger-Saldaña *et al.*, 2023) in showing that increased marginalization is inversely proportional to BC survival,

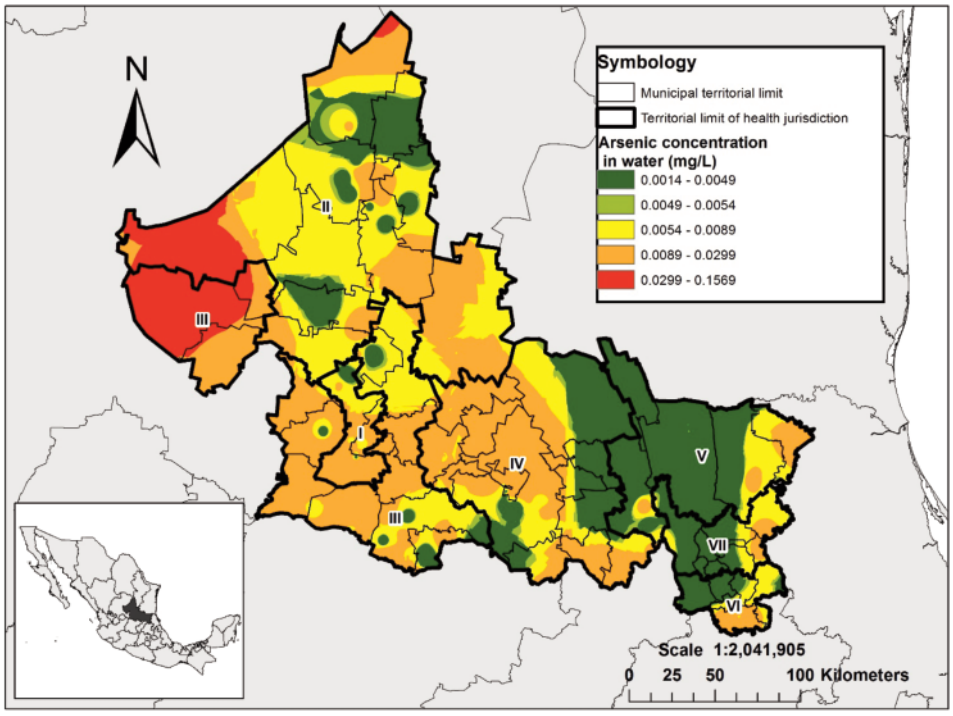


Figure 7. Geographic distribution across Health Jurisdictions I-VII of the average concentration of arsenic in water (mg/L) in San Luis Potosí State 2012-2020.

a pattern that parallels the association observed with clinical stage at diagnosis. Although marginalization itself does not cause BC, this result, this is significant because it influences its progression, as individuals facing poverty and marginalization often cannot afford healthcare costs (WHO, 2017). Consequently, marginalization becomes a critical, modifiable factor for future strategies aimed at reducing BC mortality.

The risk of recurrence has been directly associated with advanced tumour stage, particularly among women diagnosed at stages III and IV (Pérez-Michel *et al*., 2009). Recurrence, defined as the appearance of a new local or distant tumour more than one year after the initiation of treatment (Pérez-Michel *et al.*, 2009), was similar (46.5 months) to a study conducted on 119 BC cases treated at the Military Women's Hospital in Mexico City between 2010 and 2015, where Heredia-Caballero & Palacios-López (2018) found that the mean survival time among women with recurrence was 47 months.

Currently, there is a growing consensus on the importance of arsenic exposure in the development of various cancer types. However, the impact of As-W on BC survival has not been directly addressed before our work. We added this variable in our research since a study conducted in the Antofagasta Region of Chile showed a sharp decline in BC mortality rates between 1958 and 1970, while Smith et al. (2014) noted that inorganic arsenic concentrations in the local drinking water reached as high as 870 µg/L during the same period suggesting a possible protective association. Although our findings also suggested a potential protective effect against BC mortality, the results were not statistically significant. On the other hand, the arsenic concentrations recorded in Chile during that period were 5.5 times higher than the maximum levels detected in San Luis Potosí (0.1569 mg/L). This difference in exposure magnitude may partially explain the lack of statistical significance in the Log-Rank test observed in our study.

Smith *et al.* (2014) also evaluated the viability of BC cell lines exposed to varying concentrations of arsenic trioxide (As_2O_3). At 72 hours, apoptotic effects were observed at concentrations as low as 1-2 µM of As_2O_3. Arsenic trioxide is already in use for the treatment of acute promyelocytic leukemia, with its side effects well documented. The addition of our results supports the proposal made by by Smith *et al.* (2014) to initiate clinical trials investigating the use of inorganic arsenic in BC therapy.

Limitations

This work is subject to limitations related to the nature of the secondary data used, For example, health services and information from the Ministry of Health primarily reach rural and low-income women (López-Carrillo *et al.*, 2009). In addition, although the study population of women without social security comprise a substantial proportion, it does not represent the entire female population of the state. Therefore, this study may not fully capture breast cancer cases diagnosed in other healthcare institutions.

The upward trend in BC mortality described in this study, and in other national and regional reports, should serve as a public health warning, emphasizing the need to progressively expand screening coverage, particularly in light of population growth and aging, which are expected to exacerbate the burden of this disease in the future. Further research using experimental study designs is therefore recommended.

Conclusions

The development of spatial health maps through HG to analyze the distribution of BC mortality across space and time, along with the study of survival-associated factors, is crucial for understanding the geographical and temporal variations in BC mortality. This approach provides new perspectives for studying BC and may serve as a valuable tool for healthcare planning and the design of early diagnosis and screening strategies, especially in areas with higher mortality rates or where advanced stages and older age at diagnosis are most prevalent. Moreover, the estimates provided here on clinical stage and age at diagnosis as well as overall survival, may be useful for evaluating and comparing the impact of current and future BC action programs. Meanwhile, the survival outcomes stratified by stage, age at diagnosis, marginalization index and recurrence have demonstrated that these variables are statistically significant prognostic factors for BC survival. These findings contribute additional evidence to the scientific literature, supporting their consolidation as reliable prognostic indicators in BC outcomes research.

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Onine supplementary materials

Table S1. Results of the Log-Rank (Mantel–Cox) test: pair-wise comparisons and mean Kaplan–Meier survival times for each variable (chi-square (p))

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Availability of data and materials: all data generated or analyzed during this study are included in this published article.

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