Diabetes Disparities in Mexico: A Spatio-Temporal and Marginalization Index Analysis

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Abstract. Understanding the geospatial and temporal distribution of diabetes mellitus in Mexico can be an essential tool in supporting vulnerable populations and addressing health inequalities. This article presents a spatio-temporal investigation of patients aged 18 years and older with diabetes mellitus in Mexico, associated with geographical area and a temporal range from 2005 to 2022. This approach includes calculating diabetes-related hospitalizations and deaths and its association with the margination index segmented into eight geographical areas of Mexico. Furthermore, this research stratifies based upon age group and type of medical institute of the health services in Mexico. The main contribution of this research is to explore the relationship between diabetes-related hospitalizations, deaths, geographical area, age, sex, and margination index of populations to support preventive action. The results highlight that adults between the ages of 45 and 64 years old who live in areas with a high margination index have a greater likelihood of suffering complications related to diabetes. Research will now continue to explore mapping interventions to specific states and external datasets, to further extrapolate the results of the analysis.

Keywords: spatio-temporal analysis, marginalization index, geographical areas, hospitalizations, deaths, diabetes mellitus, binomial regression, association modelling.

1 Introduction

Diabetes mellitus is a 21st century challenge in worldwide public health, with the increasing number of individuals with diabetes encouraging an ongoing focus in preventative programs [1]. Based on the worldwide research context, the spatio-temporal analysis in this article enables us to measure the impact of social privations, including education, food, and essential services, on diabetes-related hospitalizations and deaths in Mexico. Diabetes is one of the most prevalent non-communicable diseases in the world, with significant increases in occurrence being identified from 1980 to 2014 [2]. Researchers have investigated the effects of various factors, analyzing them temporally from 2005 to 2022 and spatially across the eight geographical areas of Mexico, and associating to the sex, age group, and medical institute where patients are affiliated [3].

This article builds on this existing work to focus on the spatio-temporal context and marginalization to support ongoing preventive action.

The remainder of the paper is structured as follows. The next section briefly introduces the background of the project and related work; Section 3 provides the context of the work completed and describes the records of the hospitalization and death datasets. Section 4 develops the CRISP-DM methodology specific to this article, an analysis of Diabetes-relates Avoidable Hospitalizations (DRAH) and Diabetes-Related Deaths (DRD); Section 5 reports and presents the findings and results. Finally, Section 6 concludes and outlines future work which could be conducted in the spatio-temporal analysis of diabetes.

2 Background

Exploration of the association of diabetes-related hospitalizations and deaths worldwide has garnered increased health systems attention. In 2021, the World Health Organization ranked diabetes mellitus as the 8th leading cause of death worldwide [4], providing significant motivation for a continued focus on evaluating spatial disparities. Researchers have employed diverse methodologies to investigate diabetes through spatial methods, with a growing emphasis on understanding access to basic services, such as healthcare and food [5]. Common health difficulties related to diabetes mellitus include an increased risk of a heart attack or stroke and complications related to the eyes, kidneys, and nerves [6]. A brief overview of recent work and distinctions from the approach presented in this study are provided in the remainder of this section.

Due to the international and national prevalence of diabetes around the world, several researchers and projects have explored the spatio-temporal disparities between geographic regions, countries and states. For example, authors have previously explored the incidence, mortality, and risk factors of type-2 diabetes mellitus across 21 world regions from 1990-2019 through an annual average percentage change regression model [7]. Other studies have also examined the temporal aspects of diabetes to project disease and economic burden through a Bayesian model for 2020-2030 [8]. These articles highlight the impact of socio-economic and temporal changes in diabetes, and open data enables new models to be designed. A systematic review [9] highlights many studies using spatial modelling to understand diabetes outcomes, with Bayesian generalized linear mixed modelling, generalized linear modelling, and geographic information systems being used, with spatial studies being considered effective beyond the USA and Europe [9].

Recent studies have emphasized the impact of diabetes mellitus in Mexico, for example, an article on the socio-spatial vulnerability of type-2 diabetes in Mexico during 2020 found several clustered areas with high and low vulnerability to diabetes through a multiple linear regression model [10]. Similarly to worldwide approaches, authors have also investigated the spatio-temporal trends and effect of marginalization between

1990 and 2019 finding that the highest marginalization quintiles had double the risk of dying from diabetes as the lowest through the analysis of death certificates [11]. Using this existing literature as an impetus the work conducted in this article instead focuses on understanding the association between diabetes hospitalization and death alongside the margination index of Mexico.

3 Context and Data Selection

Diabetes mellitus is an Ambulatory Care Sensible Condition (ACSC), a health condition for which adequate treatment and timely intervention in the ambulatory care system could potentially avoid hospitalizations [12]. This noncommunicable disease can be managed by ensuring that individuals needing care are given access to the best information, support and education, this includes the effective measure of outcomes [13] and overall educational programs [14]. Complications of diabetes can include both short-term and long-term issues, for example, heart attacks or strokes, eye damage, and foot problems [6]. This context highlights the importance of a multi-disciplinary approach to spatially understanding diabetes mellitus, its occurrences, and disparities in care, providing impetus for the spatio-temporal analysis conducted in this article.

3.1 Data Selection

The diabetes-related International Codes of Diseases (ICD-10-CM) are listed in the specification of the prevention quality diabetes composite indicator prepared by the Agency for Healthcare Research and Quality (AHRQ) [15], PQI #93, which includes PQI #1, PQI #3, PQI #14, and PQI #16. The datasets of hospitalizations and deaths contain a variable named "principal condition", enabling the filtering of conditions in PQI #93. The research conducted in this study utilizes 26 prevention of quality ICD-10-CM codes: E101-E106, E108-E116, E118-E119, E130-E136, E138, and E139.

As part of the data selection process, medical institutes of Mexico were selected to enable analysis and comparison between varying institutes. These include: SS (Secretaría de Salud) is the public medical institute dependent on the Ministry of Health of Mexico; IMSS (Instituto Mexicano del Seguro Social) is the most extensive medical system in Mexico, which treats all officially registered employees; ISSSTE (Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado) is the medical system for government workers, accounting for more than 97% of hospitalizations; IMSS-Bienestar is a federal government program that offers free medical access to IMSS facilities; PEMEX (Petroleos Mexicanos) provides medical units for PEMEX workers; SEMAR (Secretaría de la Defensa Nacional y Secretaría de Marina) serves as the medical institute for soldiers and maritime personnel. Lastly, other public and private medical units and DIF (Sistema de Desarrollo Integral de la Familia) are classified.

4 Methodology

The methodology developed in this study represents an adaptation of the widely recognized data mining (DM) approach, specifically tailored for health data in this work. As illustrated in Fig. 1, the Cross Industry Standard Process for Data Mining (CRISP-DM) methodology comprises six stages within its data flow framework: (1) problem understanding; (2) data understanding; (3) data preparation; (4) modelling; (5) evaluation; and (6) deployment [16]. Each of these stages is adapted to the context of investigating diabetes and marginalization in the subsequent sections of this article.

The margination index measures the intensity of deprivation and social exclusion in the population. It comprises education level, access to quality housing, income levels, and access to essential services (including electric power and drainage). Each geographical area has one of the four possible margination indexes: low, medium, high, or very high, according to the National Population Council of Mexico (CONAPO, in Spanish) [17], responsible for evaluating the marginalization in Mexico. This represents a vital understanding of the problem, representing the first stage of the CRISP-DM methodology represented in Fig. 1 at point 1.

In Mexico, the Ministry of Health publishes hospitalization and death records from 2005 to 2022 through the General Department of Health Information in its open data repositories [18]. Although some records for 2023, 2024, and 2025 exist, they were excluded for being incomplete for all geographical areas, months, and medical institutes, whether public or private. Hospitalization records comprise more than 50 variables, which have increased over the years. Key variables include the identification of residence state, sex, age or age group, and ICD-10-CM code for the cause of hospitalization, rising from 1,048,576 records in 2005 to over 1,500,000 in 2022 [19]. Death records also contain more than 50 variables, and those selected for this study are residence state, sex, age, ICD-10-CM code for the cause, and place of death, increasing from 495,241 records in 2005 to 847,717 records in 2022 [20], as shown in point 2 of Fig. 1.

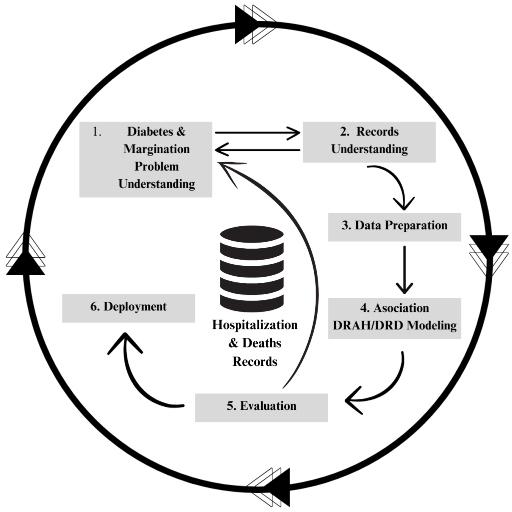

Fig. 1. A diagram representing the Cross Industry Standard Process for Data Mining (CRISP-DM) methodology which was adapted and applied to this work (Adapted from: [16]).

4.1 Data Gathering, Pre-Processing, and Preparation

The first two stages were conducted with open government data, extracting health from the General Department of Health Information of Mexico. The records were merged with the margination index per geographical area by the identifier of the residence state, according to the National Health and Nutrition Survey of Mexico in 2022 (ENSANUT, in Spanish). The 8 geographical areas and corresponding states are: (1) Pacífico Norte: Baja California, Baja California Sur, Nayarit, Sinaloa and Sonora; (2) Frontera: Chihuahua, Coahuila, Nuevo León and Tamaulipas; (3) Pacífico-Centro: Colima, Jalisco and Michoacán; (4) Centro-Norte: Aguascalientes, Durango, Guanajuato, Querétaro, San Luis Potosí and Zacatecas; (5) Centro: Hidalgo, Tlaxcala and Veracruz; (6) Ciudad de México/Estado de México: Ciudad de México and Estado de México; (7) Pacífico Sur: Guerrero, Morelos, Oaxaca and Puebla; and (8) Península: Campeche, Chiapas, Quintana Roo, Tabasco and Yucatán. Each area was associated with its corresponding margination index; therefore, only the margination indexes were taken in the association analysis due to the imminent correlation between the variables in this pre-processing stage.

In the data cleansing and preparation stage, point 3 in Fig. 1, records with outlier data and unknown sex, residence, medical institute, age, or age group were removed, averaging between 1% and 5% of rows being removed per dataset.

4.2 Data Integration, Statistical Analysis, and Exploration

This fourth stage of the CRISP-DM methodology (point 4 in Fig. 1) involves modelling the association using a binomial regression, where Diabetes-Related Avoidable Hospitalization (DRAH) is the dependent variable. The data is coded as “1” if classified as an avoidable hospitalization and “0” if it is not. For Diabetes-Related Deaths (DRD), the coding is classified as “1” if the death is due to a preventable condition related to diabetes and “0” if it is not.

Data was collected and categorized as part of the data integration and exploration stages. Fig. 2 presents bar plots of DRAH per year from 2005 to 2022, displayed as a stacked bar chart with cases represented per medical institution. Beneath each bar plot, the margination index is illustrated using grey tones; the darkest square indicates a very high margination, while the lightest square represents a low index. Fig. 3 depicts DRD at home or public places, stratified by sex and year, along with the corresponding geographical area and margination index also represented in grey tones.

The results of the statistical analysis conducted through a binomial regression of DRAH and DRD are presented in odds ratios (OR) in Table 1, including the age group of the patients, the margination indexes, and the medical institute treating the patients. To interpret these results, it is necessary to understand the baseline; for instance, in the column of characteristics in Table 1, the first entry is women, and the OR column for 2019 results in 0.66, with a confidence interval of 95%, having a lower limit of 0.65 and an upper limit of 0.67, along with a p-value < 0.0001, indicated by three asterisks (***). The baseline or exposure is men, due to the OR being a relative measure. Therefore, women are 33% less likely than men to experience the condition, with a 95% confidence level, and this is statistically significant because the p-value is less than 0.05. Table 1 displays odds ratios for DRAH and DRD for 2019 and 2020, which marks the COVID-19 breakpoint for the pandemic; beneath each value of the odds ratio are the lower and upper limits of the confidence interval to achieve a 95% confidence level.

Another example is the medical institute IMSS, which has the highest number of patients in Mexico. The baseline for this ratio is SS. The OR value for 2019 is 1.79, indicating that IMSS patients are 79% more likely than SS patients to be statistically significant.

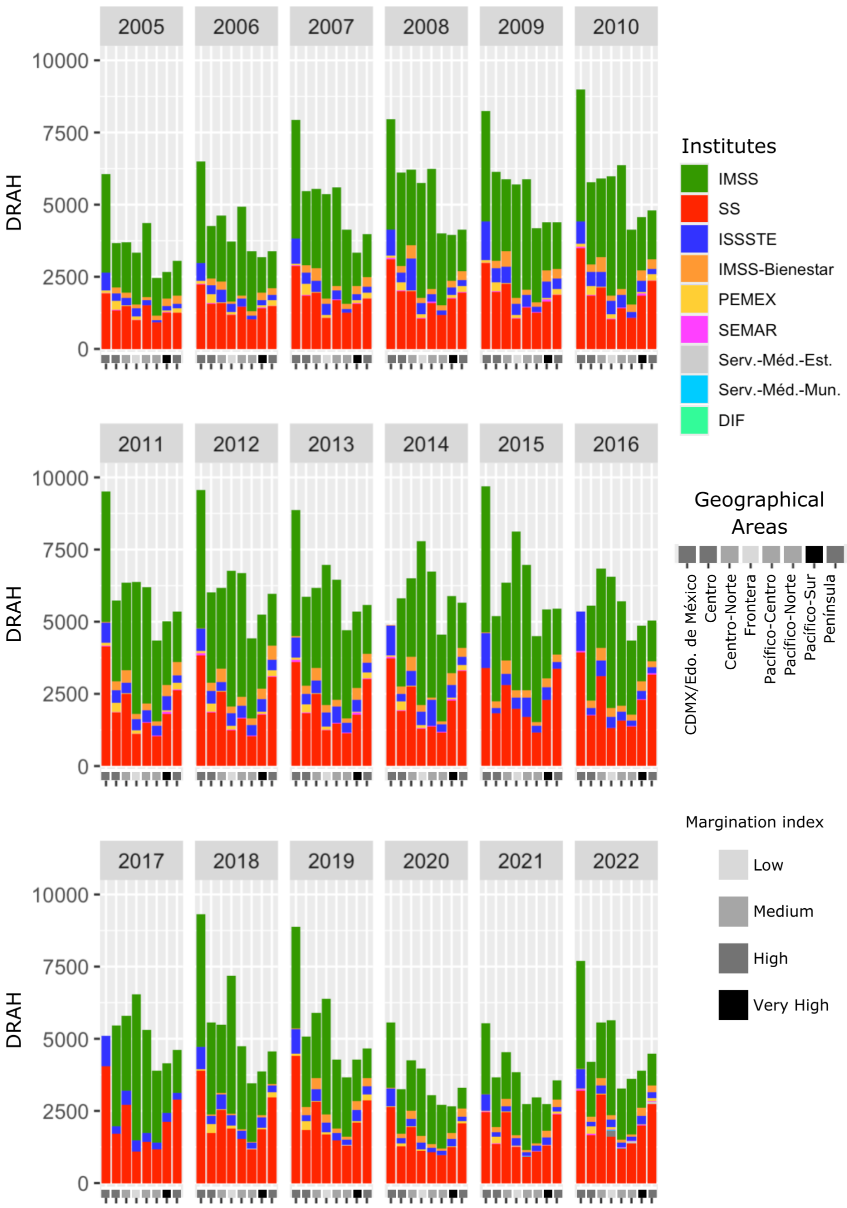

Fig. 2. Stacked spatio-temporal bar charts representing Diabetes-Related Avoidable Hospitalizations (DRAH) per year, geographical area (margination index), and medical institute.

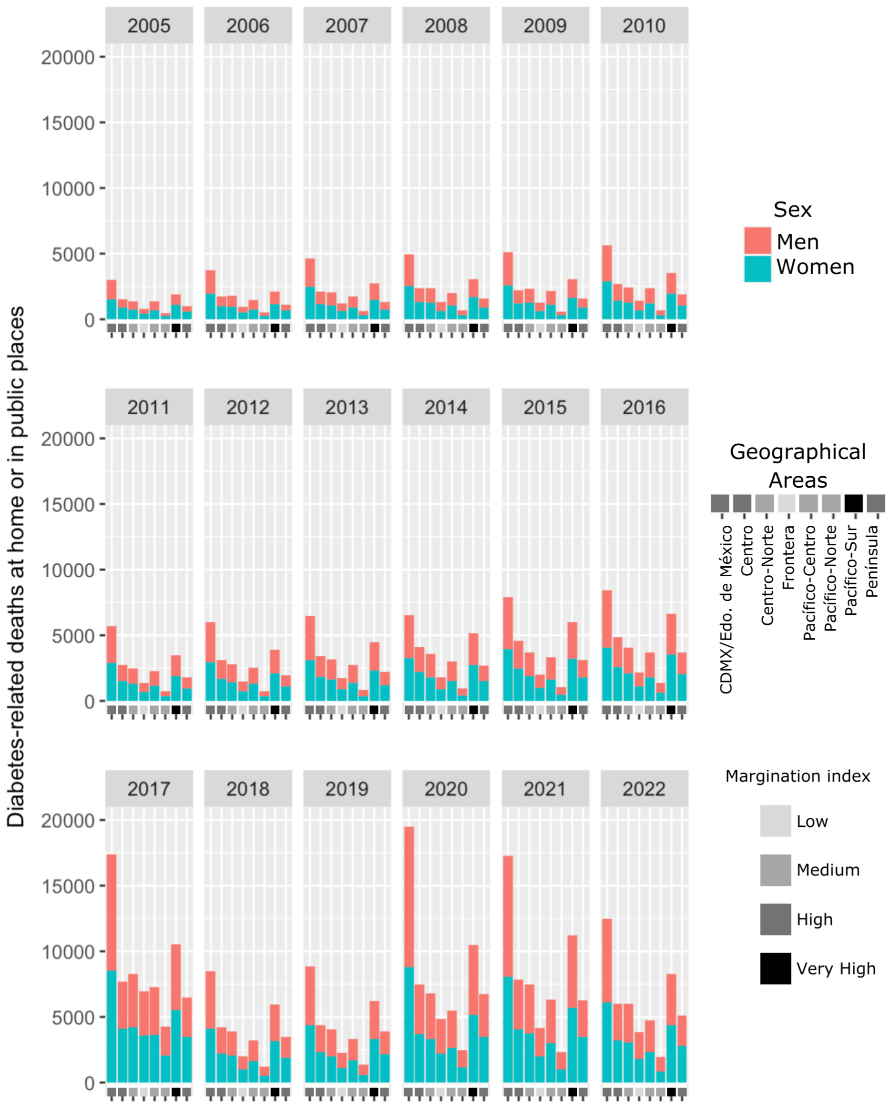

Fig. 3. Stacked spatio-temporal bar charts representing Diabetes-Related Deaths (DRD) at home or public places per year, geographical area (margination index), and institute.

Table 1. Association of Diabetes-related Avoidable Hospitalizations (DRAH) and Diabetes-related Deaths (DRD) in pre-pandemic COVID-19 and the beginning of the pandemic COVID-19 period.

	Diabetes-related Avoidable Hospitalizations		Diabetes-related Deaths	
Characteristic	**OR 2019**	**OR 2020**	**OR 2019**	**OR 2020**
Women	0.66***	0.68***	1.23***	1.21***
	0.65,0.67	0.67, 0.70	1.20, 1.26	1.18, 1.23
Age-group (years old)				
18-44	—	—		—
45-64	7.03***	6.50***	4.18***	3.47***
	6.89, 7.17	6.34, 6.66	3.93, 4.46	3.31, 3.63
+65	6.63***	6.17***	2.97***	2.46***
	6.49, 6.77	6.01, 6.33	2.80, 3.16	2.35, 2.57
Margination index				
Low	—	—	—	—
Medium	0.79***	0.94***	1.28***	1.18***
	0.77, 0.81	0.91, 0.96	1.21, 1.35	1.13, 1.22
High	0.98*	1.06***	1.83***	1.88***
	0.96, 1.00	1.03, 1.09	1.74, 1.92	1.82, 1.95
Very High	1.05***	1.08***	1.74***	1.64***
	1.02, 1.08	1.04, 1.12	1.65, 1.84	1.57, 1.70
Institute				
SS	—	—	—	—
IMSS bienestar	0.63***	0.72***	1.24***	1.10***
	0.62, 0.64	0.71, 0.73	1.20, 1.28	1.08, 1.12
IMSS	1.79***	1.91***	1.19***	1.07***
	1.73, 1.85	1.83, 1.98	1.13, 1.25	1.04, 1.11
ISSSTE	0.48***	0.61***	0.98	0.78***
	0.47, 0.50	0.59,0.63	0.85, 1.13	0.70, 0.87
PEMEX	0.58***	0.52***	1.43***	1.02
	0.54, 0.61	0.48, 0.57	1.22, 1.67	0.90, 1.16
SEDENA		0.32***	1.11	0.94***
		0.18,0.52	0.81, 1.49	0.74, 1.19
SEMAR	0.21***		1.18***	1.04*
	0.14, 0.30		1.15, 1.22	1.01,1.07
Other (public)		0.06***	1.16**	1.08*
		0.01, 0.20	1.06, 1.27	1.01, 1.14
Other (private)		5.19***	0.85	0.74***
		1.84, 11.4		0.64, 0.84

5 Results

The analysis produced using the adapted CRISP-DM methodology presented several interesting findings related to DRAH. When analyzing the data per year, geographical area, and medical institute; we observe that for CDMX/Edo. de México, being the most crowded metropolitan area, with more than 20 million people, presents through the years the highest numbers of avoidable hospitalizations among the geographical areas analyzed. Stacked bar plots of DRAH are shown in Fig. 4 with the number of cases per medical institute; for example, Península, an area geographically with a high margination index, shows that most people have SS as medical services (red area in bar stacked in bottom-right at Fig. 4), representing the key variations of the data analyzed during this study.

Observing the behavior before and after COVID-19 is of note. From 2005, there were upward trends generally until 2015, and then, in 2018, beginning with downward trends until 2020. A possible explanation is COVID-19, but some years before, the trends decreased for other reasons, possibly due to other public health campaigns or programs. Fig. 4 presents that DRD in 2020 at home or in public places across all geographical areas increased, possibly due to the impact of COVID-19. Therefore, deaths increased while DRAH decreased. As illustrated in Fig. 4, DRD showed a gradual increase in equal proportions for both men and women from 2005 to 2020. It abruptly increased with the onset of the COVID-19 pandemic, followed by a decline that continued until 2022. The results from this study encourage the further exploration of these associations upon more recent datasets becoming available.

Temporally, Table 2 displays ORs for five-year periods: 2005, 2010, 2015, and 2020, while also including 2019 and 2022 to illustrate the trends of the DRAH with its associated factors. For women, the likelihood of being hospitalized due to a diabetes-related condition is lower than for men, ranging from 10% to 38%. For the age group, people between 45 and 64 have a higher likelihood of being a DRAH than younger people while showing similar results to those older. The impact of the margination index reveals that a high index generates 40% more likelihood than those areas with a low index. For the medical institute, people affiliated with the IMSS have a 34% higher likelihood than people who use SS medical services. All other medical services analyzed in this article have a lower likelihood.

In the case of DRD, for women, the likelihood is more significant than for men, on average 25% more. For age groups, this is similar to DRAH; people aged between 44 to 64 years old have a 300% more likelihood over younger people and double that of older people. For the margination index, individuals who live in an area with a high or very high index of margination have an 83% more likelihood than the remaining lower index areas. Finally, for medical institutes, SS is the baseline and people affiliated with other medical services have a higher likelihood, on average 50%. These medical services have a higher impact on DRD.

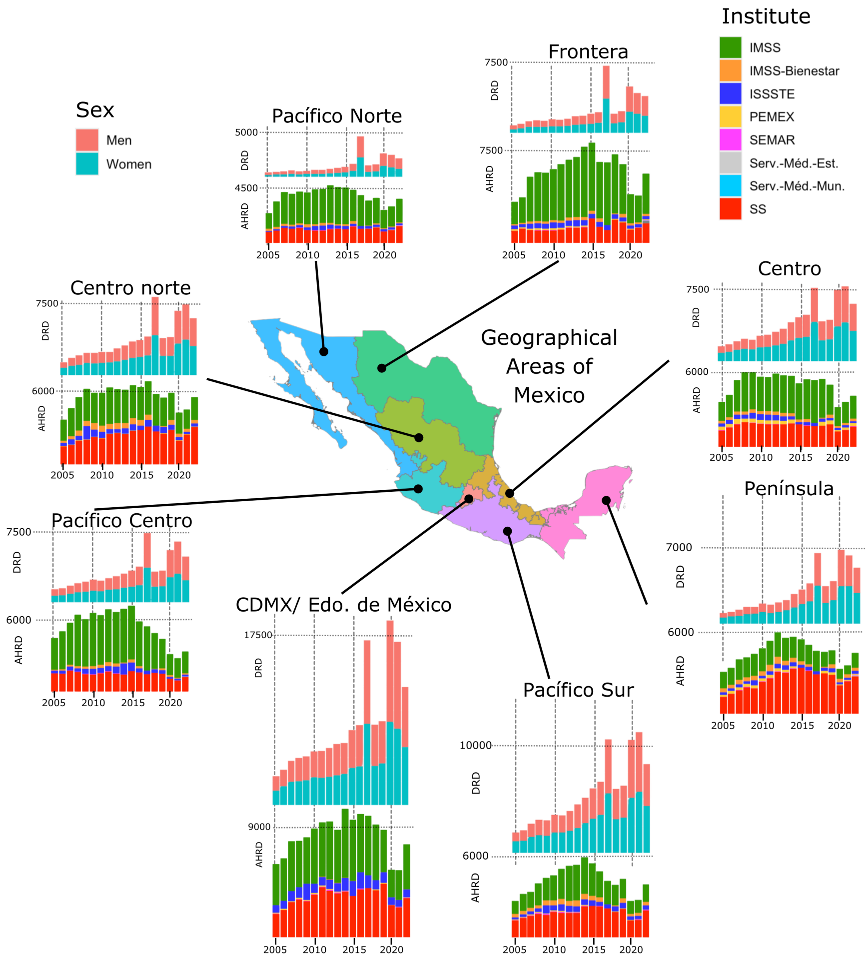

Fig. 4. Avoidable Hospitalization Related to Diabetes (AHRD) by the institute and Deaths Related to Diabetes at home or in public places (DRD) by sex, per year, and geographical area.

6 Conclusions

This article investigated the association of diabetes mellitus with DRAH and DRD, incorporating health records of open datasets of hospitalizations and deaths. The work highlighted the spatio-temporal differences of the pre-pandemic and pandemic COVID-19 period, revealing that DRD increased in almost all geographical areas. At the same time, the DRAH decreased at the beginning of the pandemic, years 2020 and 2021. Also, the margination index, which is related to poverty, is not a determinant factor contributing to the cases of DRAH or DRD. It is crucial to observe that hospitalization has decreased, in general, since 2017, and abruptly in the first months of 2020, possibly due to COVID-2019. It is essential to highlight the high association between DRAH and DRD for people aged between 45-64 years old with a high margination index. In other words, based on this analysis, if your residence is the Península, Pacífico Sur or CDMX/Edo. de México; you are 45-64 years old; and you are affiliated with IMSS you have a higher likelihood of requiring the hospital or suffering a death related to diabetes.

This research also opens opportunities for further investigation by incorporating additional variables, such as environmental factors and specific air and water contamination indexes, to evaluate the impact on preventable hospitalizations and deaths across geographical areas. Another ongoing effort is to analyze the data by state rather than by geographical area or through incorporating discrete global grid systems. Additionally, the implementation of classifiers and prediction algorithms is being considered to further supplement the analysis in this study.

Table 2. Association of age-group, Margination Index and Medical Institute with Diabetes-Related Avoidable Hospitalizations, 2005, 2010, 2015, 2019, 2020 and 2022.

Characteristic	Diabetes-Related Avoidable Hospitalization (DRAH) Odd Ratio (OR)					
	2005	**2010**	**2015**	**2019**	**2020**	**2022**
Women	0.90	0.78	0.70	0.66	0.68	0.62
Age-group (years old)						
18-44	—	—	—	—	—	—
45-64	11.4	10.4	9.08	7.03	6.50	5.72
+65	11.8	10.5	8.88	6.63	6.17	5.26
Margination index						
Low	—	—	—	—	—	—
Medium	1.32	1.15	0.84	0.79	0.94	0.80
High	1.39	1.25	0.92	0.98	1.06	*
Very High	1.28	1.21	*	1.05	1.08	1.16
Institute						
SS	—	—	—	—	—	—
IMSS bienestar	0.76	1.08	0.89	0.63	0.72	0.61
IMSS	1.34	2.06	1.72	1.79	1.91	1.56
ISSSTE	0.44	0.58	0.60	0.48	0.61	0.45
PEMEX	0.73	0.56		0.58	0.52	0.51
SEDENA	0.69	0.77		0.21		1.16
SEMAR					0.32	0.56
Other (public)					0.06	
Other (private)					5.19	

Note: * p-value >= 0.05.

Table 3. Association of age groups, margination index and medical institute with diabetes-related deaths, 2005, 2010, 2015, 2019, 2020 and 2022.

Characteristic	Diabetes-Related Deaths (DRD)					
	Odd Ratio (OR)					
	2005	**2010**	**2015**	**2019**	**2020**	**2022**
Women	1.30	1.29	1.25	1.23	1.21	1.21
Age-group (years old)						
18-44	—	—	—	—	—	—
45-64	4.27	4.64	4.69	4.18	3.47	4.08
+65	2.85	2.98	3.08	2.97	2.46	3.02
Margination index						
Low	—	—	—	—	—	—
Medium	1.40	1.33	1.41	1.28	1.18	1.20
High	1.84	1.86	1.92	1.83	1.88	1.75
Very High	1.84	1.83	1.97	1.74	1.64	1.56
Institute						
SS	—	—	—	—	—	—
IMSS bienestar	1.69	1.67	1.49	1.24	1.10	1.10
IMSS	1.47	1.48	1.42	1.19	1.07	1.08
ISSSTE	1.31	1.10	1.25	0.98	0.78	0.84
PEMEX	2.12	2.42	1.52	1.43	1.02	1.21
SEDENA	1.32	1.47	1.85	1.11	0.94	1.06
SEMAR	1.47	1.40	1.28	1.18	1.04	1.06
Other (public)	1.28	1.24	1.14	1.16	1.08	1.02
Other (private)			1.02	0.85	0.74	1.05

Note: * p-value >= 0.05.

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