# From Social Determinants to Health Outcomes: A Comprehensive Study of Puerto Rican Adults

A Dissertation Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Rebeca Nicole Nieves

May 2026

Copyright © 2026 By Rebeca Nicole Nieves Rodríguez

All rights reserved.

## Dedication

*Para todas aquellos que dejaron atrás a sus familias y sus países para perseguir sus sueños. Boricua que me lee, Puerto Rico es más grande que 100 millas por 35 millas; no existe nada que no podamos lograr.*

(To all those who left their families and their countries to follow their dreams. Boricua who reads this, Puerto Rico is much bigger than 100 miles by 35 miles; there is nothing we cannot achieve.)

**Acknowledgements**

I would like to express my gratitude to my dissertation committee and mentors for their invaluable guidance, thoughtful feedback, and unwavering support throughout this journey. To Dr. Thankam Sunil, thank you for encouraging me to approach challenges from new perspectives and for helping me find solutions when I struggled to see a way forward. To Dr. Brittany Shelton, thank you for your words of encouragement, new insights, and continued support. To Dr. Jiangang Chen, thank you for introducing me to a new way of understanding public health; without your Global Public Health class seven years ago, I may never have discovered my passion for this field. To Dr. Alejandro Vázquez and Dr. Cynthia Navarro Flores, words cannot fully capture my gratitude. Your kindness, expertise, and support were a lifeline when I needed it most, and this past year under your mentorship has shaped both my personal and professional growth in lasting ways.

To my parents, I can never thank you enough for the sacrifices you have made to help me pursue my dreams. Your constant belief in my potential and your encouragement to go beyond it have meant everything. To my siblings, thank you for reminding me of the strength I will always find with you—especially in moments filled with laughter. To my friends, thank you for your kindness and love, but most importantly, for simply being there. To my cat, Tsuki, words cannot express how much your companionship has meant to me. Even when my family moved back to Puerto Rico, I knew I was never truly alone because I had you. With all the late nights you spent studying beside me, you've certainly earned a degree of your own. Finally, to Seven Seas Beach in Fajardo, Puerto Rico: thank you for being a place of reflection and clarity, where so many of my most meaningful decisions were made. In my hardest moments, my mind often returned to your shores. Now, it is time to return and simply appreciate how far I have come.

## Abstract

Social determinants of health (SDOH) are non-medical factors that shape individual and population health outcomes, including the conditions in which people are born, live, and age, as well as broader social and structural systems. A substantial body of research shows that SDOH are among the strongest drivers of health disparities, often exceeding the influence of medical care. However, gaps remain in understanding how multiple determinants operate together across diverse health outcomes within specific populations. Puerto Rico provides a critical context for examining these relationships given its unique socioeconomic conditions and persistent health inequities. This dissertation examined how multiple SDOH are associated with health outcomes among Puerto Rican adults.

In Chapter II, regression analyses were used to assess associations between SDOH and self-rated general, physical, and mental health. Factors such as education, employment, income, and access to care were significantly associated with poorer health outcomes. In Chapter III, elastic net models evaluated how combinations of correlated SDOH classify chronic and behavioral health outcomes. Results showed modest predictive performance, with key determinants—including financial hardship, stress, and transportation barriers—consistently contributing to risk classification. In Chapter IV, latent class analysis identified distinct SDOH profiles within the population. Four subgroups emerged, reflecting varying levels of material hardship and psychosocial stress. Individuals in higher-need groups experienced significantly worse chronic, mental, and behavioral health outcomes compared to those in lower-need groups.

This dissertation contributes to the growing body of literature demonstrating that health outcomes are deeply embedded within broader social and structural contexts. By integrating traditional regression, machine learning, and person-centered approaches, this work provides a

more comprehensive understanding of how SDOH influence health in Puerto Rico. These findings highlight the importance of addressing both material and psychosocial conditions and support the need for targeted, population-specific interventions to reduce health disparities.

## Table of Contents

Chapter I: Introduction ..... 1

References ..... 10

Chapter II: Más Allá de las Circunstancias: Social Determinants of Health and Self-Rated, Physical, and Mental Health Among Puerto Rican Adults ..... 14

Abstract ..... 15

References ..... 36

Appendix (Tables) ..... 40

Supplemental (Tables) ..... 44

Chapter III: ¿Detrás del síntoma, el sistema? Relative Importance of Social Determinants of Health in Classifying Health and Behavioral Outcomes Among Puerto Rican Adults ..... 46

Abstract ..... 47

References ..... 66

Appendix (Tables and Figures) ..... 73

Supplemental (Tables) ..... 78

Chapter IV: Vidas en Contexto: Unpacking Social Determinants of Health and Related Health Outcomes among Puerto Ricans through a Person-centered Approach ..... 80

Abstract ..... 81

References ..... 104

Appendix (Tables and Figures) ..... 112

Supplemental (Tables and Figures) ..... 117

Chapter V: Conclusion ..... 121

References ..... 132

Vita ..... 135

## List of Tables

**Table 1.1** Imputed Demographic and SDOH Characteristics of the Sample (n = 4,594) ..... 40

**Table 1.1** Imputed Demographic and SDOH Characteristics of the Sample (n = 4,594) (Continued) ..... 41

**Table 1.2** Associations Between Social Determinants of Health and Self-Reported General, Physical, and Mental Health Among Puerto Rican Adults (n = 4,594) ..... 42

**Table 2.1** Imputed SDOH, Chronic Disorders, and Indicators of Wellbeing and Behavioral Health ..... 73

**Table 2.1** Imputed SDOH, Chronic Disorders, and Indicators of Wellbeing and Behavioral Health (Continued) ..... 74

**Table 2.2** Classification Performance of Final LASSO Logistic Regression Models Across Health Outcomes ..... 75

**Table 3.1** Fit Statistics for Latent Class Analyses ..... 112

**Table 3.2** Sample Demographics by SDOH Latent Class Membership with Missing Data Imputation ..... 113

**Table 3.3** SDOH Latent Classes by Health Outcomes with Missing Data Imputation ..... 114

**Table 3.3** SDOH Latent Classes by Health Outcomes with Missing Data Imputation (Continued) ..... 115

## List of Figures

**Figure 2.1** Tetrachoric Correlations Among SDOH and Health Outcomes ..... 76

**Figure 2.2** Elastic Net Variable Importance for Classifying Health Outcomes from SDOH ..... 77

**Figure 3.1** SDOH Four-Class Solution ..... 116

## List of Supplemental Tables and Figures

**Supplemental Table 1.1** Unimputed Demographic and SDOH Characteristics of the Sample (n = 4,594) ..... 44

**Supplemental Table 1.1** Unimputed Demographic and SDOH Characteristics of the Sample (n = 4,594) (Continued) ..... 45

**Supplemental Table 2.1** Unimputed SDOH, Chronic Disorders, and Indicators of Wellbeing and Behavioral Health ..... 78

**Supplemental Table 2.1** Unimputed SDOH, Chronic Disorders, and Indicators of Wellbeing and Behavioral Health (Continued) ..... 79

**Supplemental Table 3.1** Unimputed Sample Demographics ..... 117

**Supplemental Table 3.2** SDOH, Chronic Disorders, and Indicators of Wellbeing and Behavioral Health ..... 118

**Supplemental Figure 3.1** Logistic Regression Analyses: SDOH Class Membership Associations with Individual Health Outcomes ..... 119

**Supplemental Figure 3.2** Logistic Regression Analyses: SDOH Class Membership Associations with Behavioral Health Outcomes ..... 120

## List of Abbreviations and Symbols

| | |
|---|---|
| SDOH | Social Determinants of Health |
| SRH | Self-Rated Health |
| NIMHD | National Institute of Minority Health and Health Disparities |
| BRFSS | Behavioral Risk Factor Surveillance Survey |
| ELA | Elastic Net Analysis |
| LCA | Latent Class Analysis |

# Chapter I

## Introduction

Health outcomes are not distributed randomly across populations, nor are they determined solely by biological or individual behavioral factors. Research shows that health is substantially influenced by the social determinants of health (SDOH), which are the structural conditions in which people are born, grow, live, work, and age, systematically driving health inequities across populations (World Health Organization). These have been estimated to account for up to 55% of health variation in high-income populations, with some suggesting up to 70-80%, partially explaining persistent health inequities across populations (Braveman & Gottlieb, 2014; Chelak & Chakole, 2023). Given this, understanding health inequities requires an understanding of the broader historical and structural factors shaping these outcomes.

The conceptual foundation of SDOH emerged in response to the limitations of biomedical models that emphasized individual pathology while neglecting social context (Braveman & Gottlieb, 2014). Globally, SDOH has been used to explain persistent and widening disparities in health outcomes across and within countries. Research has consistently found associations between income inequality, educational attainment, employment, housing quality, food security, and environmental exposures to population-level health outcomes, including life expectancy, chronic disease prevalence, and infant mortality (Braveman & Gottlieb, 2014). These determinants are not independent of one another, rather, they cluster in ways that reflect broader political and economic systems. As a result, populations facing sustained structural disadvantages experience a disproportionate burden of disease (Kuh et al., 2003).

A growing body of literature emphasizes that SDOH must be understood historically, as the cumulative product of social processes developing over time. Particularly as health outcomes

observed in the present often reflect the long-term effects of historical contexts such as colonialism, land dispossession, and oppressive economic systems (Wallington & Feger, 2025). For example, colonial economies frequently reorganized local production toward export-oriented agriculture or resource extraction, increasing economic dependency which ultimately worsened long-term health vulnerabilities (Beckfield & Krieger, 2009). Geography and place are also central to SDOH frameworks. Physical location influences exposure to environmental hazards and vulnerability to climate-related events (IPCC, 2022). For example, island and coastal regions face heightened risks related to climate change, energy dependence, and infrastructure fragility, which can further worsen existing social and economic inequities (IPCC, 2022). When geographic vulnerability intersects with constrained political power or economic dependency, health risks are often intensified.

While the SDOH framework has been applied across a wide range of global contexts, Puerto Rico represents a critical case for examining the association between social determinants and population health due to its unique and, oftentimes, overlooked position. As neither an independent nation nor a U.S. state, Puerto Rico is a U.S. territory subject to external political authority and constrained self-determination (Puerto Rico | US House of Representatives: History, Art & Archives, n.d.). This political status has had profound implications for economic development, social policy, infrastructure development, and public health decision-making which all contribute to various SDOH domains (Beckfield & Krieger, 2009). Furthermore, Puerto Rico demonstrates how SDOH are shaped through historical trajectories rooted in colonialism. Since becoming a U.S. territory in 1898, Puerto Rico's social and economic conditions have been shaped by federal laws, development strategies, and governance structures over which island residents have limited political representation or voting power (Puerto Rico |

US House of Representatives: History, Art & Archives, n.d.). This has resulted in trends related to education, employment, poverty, infrastructure, and population health which cannot be fully understood without contextualizing them within the island's evolving political and economic relationship with the United States.

Puerto Rico exemplifies the challenges in each SDOH domain, including poverty affecting over 40% of residents, long-standing infrastructure deficiencies, limited access to high-quality healthcare, and repeated exposure to environmental disasters (Adler et al., 2016; Frontera-Escudero et al., 2023; Lafarga Previdi & Vélez Vega, 2020; United States Census Bureau QuickFacts, n.d.). These challenges significantly drive higher prevalence and mortality rates of chronic diseases—such as diabetes, asthma, and cardiovascular conditions—in comparison to the U.S. (Lafarga Previdi & Vélez Vega, 2020). Additionally, the average household income in Puerto Rico is significantly lower than the U.S. average, highlighting the financial imbalances restricting healthcare access and overall well-being (Frontera-Escudero et al., 2023; Lafarga Previdi & Vélez Vega, 2020). Previous studies suggest that these health inequities are tied to the island's political and colonial ties to the U.S., which create systemic barriers to essential resources (McSorley et al., 2024). This dynamic has led to persistent healthcare budget deficits, the lack of implementation of federal benefits like the Affordable Care Act, and a disjointed medical infrastructure (Portela & Sommers, 2015). Consequently, scholars propose that colonialism acts as a primary SDOH in Puerto Rico, dictating the economic and social environments that sustain long-term disparities (Martin & Pace, 2025; McSorley et al., 2024).

As a U.S. territory, Puerto Rico was placed under U.S. governance without full political representation, including the absence of voting power in Congress or presidential elections

(Puerto Rico | US House of Representatives: History, Art & Archives, n.d.). This territorial arrangement has constrained local authority over trade, labor, fiscal policy, and infrastructure investment. Federal policies such as the Jones Act have further shaped economic conditions by regulating maritime trade and increasing the cost of goods, with downstream effects on poverty, food security, and household resources (Hillberry et al., 2024). In recent decades, issues such as economic stagnation in addition to the fiscal crisis have contributed to high poverty rates, population decline, deteriorating water and energy systems, and intensified outmigration, particularly among working-age and educated residents (Varas-Díaz et al., 2023). Additionally, recurrent natural disasters have further exposed the fragility of these systems, highlighting how long-standing political and economic constraints translate into current health risks.

Puerto Rico's unique political status, combined with decades of economic dependency, constrained self-governance, and recurrent environmental crises has produced enduring social and structural inequities that shape population health. Persistent poverty, fragile infrastructure, population decline, and unequal access to resources demonstrate that health outcomes cannot be understood solely through individual behaviors or clinical interventions. Rather, these are rooted in broader social determinants. Addressing these inequities is not only a matter of public health research but also a critical step toward informing policy and practice that can improve the well-being of Puerto Rican communities. This project aims to:

1. Assess the association between key SDOH factors and self-rated general, physical, and mental health.
2. Evaluate the predictive value of SDOH in relation to objective physical, mental, and behavioral health outcomes.

3. Identify distinct clusters of SDOH needs in relation to objective physical, mental, and behavioral health outcomes.

The next three chapters of this dissertation (Chapters II, III, and IV) are manuscripts formatted for publication submission. The first manuscript (Chapter II) addresses Aim 1. It involves a quantitative, secondary data analysis to identify social determinants most strongly linked to self-rated health indicators. The second manuscript (Chapter III) addresses Aim 2 by using a quantitative, secondary data analysis to identify high value SDOH best predicting of objective health outcomes. The third manuscript (Chapter IV) addresses Aim 3 with a quantitative, secondary data analysis to assess patterns of unmet social needs within Puerto Rico and how these relate to objective health outcomes. The last chapter (Chapter V) will conclude and summarize the dissertation.

In Manuscript 1, data were drawn from the 2023 Behavioral Risk Factor Surveillance System (BRFSS), a nationally representative survey of adults aged 18 years and older in the U.S., Puerto Rico, the U.S. Virgin Islands, the District of Columbia, and Guam (CDC, 2024). The BRFSS collects information on health behaviors, preventive care, healthcare access, and chronic conditions, while also addressing emerging public health concerns such as vaccine shortages and influenza-like illnesses. Data were collected between July and December 2023 via computer-assisted telephone interviewing (CATI), with participants recruited through random-digit dialing of landlines and cell phones. Verbal informed consent was obtained, and analyses were approved by the University of Tennessee, Knoxville Institutional Review Board as non-human subjects research.

Demographic variables included age (collapsed into 18–34, 35–54, and ≥55 years), sex, income (<$25,000 vs. ≥$25,000, based on the Puerto Rico median), educational attainment, and

marital status (married, divorced/widowed/separated, never married, unmarried couple). Race and ethnicity were not included because >99% of respondents identified as Hispanic. Ten dichotomous indicators captured social determinants of health (SDOH), including life dissatisfaction, limited emotional support, loneliness, employment instability, food insecurity, food assistance, difficulty paying bills, threatened utility loss, transportation barriers, and perceived stress. Health outcomes included self-rated general health (excellent/very good/good vs. fair/poor) and the number of physically and mentally unhealthy days in the past 30 days.

Descriptive results indicated that participants were predominantly female (62.5%) and older, with 46.9% aged ≥55 years. Over half reported household incomes under $25,000 (53.3%), and most had some college education or higher (64.1%). Marital status was distributed as 37.5% married, 26.0% divorced/widowed/separated, 25.4% never married, and 11.1% unmarried couples. SDOH indicators were common, with 44.4% receiving food assistance, 22.1% reporting food insecurity, 10.4% reporting employment difficulties, and 35.4% reporting loneliness. Self-rated general health was classified as excellent/very good/good by 67.1% of participants, with fair/poor reported by 32.9%. Average poor physical and mental health days were 14.5 (SD = 11.1) and 15.7 (SD = 11.0), respectively.

In unadjusted analyses, life dissatisfaction, limited emotional support, loneliness, food insecurity, food assistance, transportation barriers, and frequent stress were all significantly associated with lower odds of reporting excellent/very good/good general health. After adjusting for demographic covariates, these associations remained significant, with transportation barriers, life dissatisfaction, and stress emerging as the strongest predictors. Older age and lower income were associated with poorer self-rated health, whereas higher education predicted better outcomes. For physically unhealthy days, life dissatisfaction, transportation barriers, and stress

were associated with more reported days, with older age also predicting greater physical health burden and higher income and education associated with fewer unhealthy days. For mentally unhealthy days, life dissatisfaction and stress were strongest, with additional effects for income, education, and marital status. These findings underscore the consistent role of life dissatisfaction, stress, and transportation barriers in shaping self-rated, physical, and mental health outcomes.

Manuscript 2 examined the same BRFSS dataset restricted to Puerto Rico (n = 4,594) to assess how SDOH collectively predict chronic and behavioral health outcomes. The most prevalent SDOH were food assistance (44.3%), social isolation (35.4%), and food insecurity (22.2%), while low life satisfaction (4.4%) and threatened utility loss (7.9%) were least common. The most common chronic conditions included arthritis (28.2%), asthma (61.8%), and diabetes (18.8%), with lower prevalence for kidney disease, stroke, and skin cancer. Behavioral health indicators included alcohol use (32.5%), current cigarette use (7.4%), and e-cigarette use (1.7%). Tetrachoric correlations indicated moderate relationships among financial hardship indicators, as well as between emotional and social measures. Health outcomes were less strongly correlated with SDOH, although depression was notably linked to low life satisfaction, loneliness, and stress.

Elastic Net logistic regression models evaluated the classification accuracy of SDOH across 14 health and behavioral outcomes. Model performance varied by outcome, with the highest AUC for depression (AUC = 0.77; sensitivity = 0.75, specificity = 0.68) and the lowest for melanoma (AUC = 0.52). Employment loss, food-related hardship, perceived stress, and transportation barriers were consistently among the top predictors across outcomes, though the relative importance of specific SDOH differed by condition. Cardiovascular outcomes were influenced primarily by employment loss and food-related hardship, respiratory outcomes by

stress, food insecurity, and loneliness, cancer outcomes by employment, food insecurity, life dissatisfaction, and emotional support, and behavioral outcomes by combinations of employment, food assistance, stress, and life dissatisfaction. These findings demonstrate that multiple SDOH collectively shape health risks, with different determinants predominating across health domains.

Manuscript 3 used latent class analysis to identify patterns of SDOH within the Puerto Rico BRFSS sample. Four subgroups emerged: Low Needs (n = 2,856), Material Scarcity (n = 798), Unmet Support and Stress (n = 701), and General Unmet Needs (n = 239). The General Unmet Needs group consistently reported the highest prevalence of all SDOH indicators, the greatest number of chronic conditions, and the most days of poor physical and mental health. Logistic regression analyses indicated that membership in higher-need classes was associated with increased odds of most chronic health conditions, depression, and substance use, whereas Material Scarcity and Unmet Support and Stress were associated with elevated odds for specific conditions, including asthma, depression, kidney disease, diabetes, and tobacco/e-cigarette use. These results highlight the cumulative burden of social adversity, showing how material and psychosocial stressors jointly influence physical, mental, and behavioral health among adults in Puerto Rico.

Taken together, this dissertation demonstrates the critical role of social determinants in shaping health disparities in Puerto Rico. Findings from Manuscript 1 emphasize life dissatisfaction, stress, transportation barriers, and food-related hardship as consistent predictors of self-rated, physical, and mental health outcomes. Manuscript 2 shows how multiple SDOH collectively influence chronic and behavioral health outcomes, with employment instability, food insecurity, stress, and social isolation as particularly high-priority vulnerabilities. Manuscript 3

highlights cumulative social adversity, demonstrating that adults experiencing multiple unmet social needs carry the greatest burden of physical, mental, and behavioral health problems. Collectively, these studies provide robust evidence to guide public health practitioners, policymakers, and community organizations in designing targeted interventions, allocating resources, and implementing programs to reduce social inequities and improve health outcomes in this high-risk population.

## References


Adler, N. E., Cutler, D. M., Fielding, J. E., Galea, S., Glymour, M. M., Koh, H. K., & Satcher, D. (2016). Addressing social determinants of health and health disparities: A vital direction for health and health care. National Academy of Medicine Perspectives.

Bombak, A. E. (2013). Self-rated health and public health: A critical perspective. Frontiers in Public Health, 1, 15. https://doi.org/10.3389/fpubh.2013.00015

Beckfield, J., & Krieger, N. (2009). Epi + demos + cracy: linking political systems and priorities to the magnitude of health inequities–evidence, gaps, and a research agenda. Epidemiologic reviews, 31, 152–177. https://doi.org/10.1093/epirev/mxp002

Braveman, P., & Gottlieb, L. (2014). The social determinants of health: it's time to consider the causes of the causes. Public health reports (Washington, D.C. : 1974), 129 Suppl 2(Suppl 2), 19–31. https://doi.org/10.1177/00333549141291S206

Centers for Disease Control and Prevention. (2024, February 9). Behavioral Risk Factor Surveillance System (BRFSS). U.S. Department of Health and Human Services. https://www.cdc.gov/brfss/index.html

Chelak, K., & Chakole, S. (2023). The Role of Social Determinants of Health in Promoting Health Equality: A Narrative Review. Cureus, 15(1), e33425. https://doi.org/10.7759/cureus.33425

Frontera-Escudero, I., Bartolomei, J. A., Rodríguez-Putnam, A., & Claudio, L. (2023). Sociodemographic and health risk factors associated with health-related quality of life among adults living in Puerto Rico in 2019: a cross-sectional study. BMC public health, 23(1), 2150. https://doi.org/10.1186/s12889-023-17115-3

Idler, E. L., & Kasl, S. (1991). Health perceptions and survival: Do global evaluations of

health status really predict mortality? *Journal of Gerontology*, *46*(2), S55–S65. https://doi.org/10.1093/geronj/46.2.S55

IPCC, 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

Hillberry, R. H., Cases J., Manuel F. (2024) Economic Consequences of Cabotage Restrictions: The Effect of the Jones Act on Puerto Rico (English). Policy Research working paper; no. WPS 10780; PROSPERITY Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/099257005212415735

Kuh, D., Ben-Shlomo, Y., Lynch, J., Hallqvist, J., & Power, C. (2003). Life course epidemiology. Journal of epidemiology and community health, 57(10), 778–783. https://doi.org/10.1136/jech.57.10.778

Lafarga Previdi, I., & Vélez Vega, C. M. (2020). Health Disparities Research Framework Adaptation to Reflect Puerto Rico's Socio-Cultural Context. International journal of environmental research and public health, 17(22), 8544. https://doi.org/10.3390/ijerph17228544

Portela, M., & Sommers, B. D. (2015). On the Outskirts of National Health Reform: A Comparative Assessment of Health Insurance and Access to Care in Puerto Rico and the United States. The Milbank quarterly, 93(3), 584–608. https://doi.org/10.1111/1468-0009.12138

Puerto Rico | US House of Representatives: History, Art & Archives. (n.d.). https://history.house.gov/Exhibitions-and-Publications/HAIC/Historical-Essays/Foreign-Domestic/Puerto-Rico/#:~:text=The%20predominant%20development%20in%20the,new%20layer%20of%20uncertainty%20instead.&text=Primarily%20as%20a%20result%20of,part%20of%20his%20patron's%20family.%E2%80%9D

Martin, J. N., & Pace, T. W. W. (2025). Colonialism as a Social Determinant of Health in Puerto Rico: Using the Socioecological Model to Examine How the Jones Act Impacted Health After Hurricane María. Journal of transcultural nursing: official journal of the Transcultural Nursing Society, 36(1), 8–15. https://doi.org/10.1177/10436596241274123

McSorley, A. M., Rivera-González, A. C., Mercado, D. L., Pagán, J. A., Purtle, J., & Ortega, A. N. (2024). United States Federal Policies Contributing to Health and Health Care Inequities in Puerto Rico. American journal of public health, 114(S6), S478–S484. https://doi.org/10.2105/AJPH.2024.307585

Murata, C., Kondo, T., Tamakoshi, K., Yatsuya, H., & Toyoshima, H. (2006). Determinants of self-rated health: Could health status explain the association between self-rated health and mortality? *Archives of Gerontology and Geriatrics*, *43*(3), 369–380. https://doi.org/10.1016/j.archger.2006.01.002

National Institute on Minority Health and Health Disparities (2025). NIMHD Research Framework. Retrieved from https://nimhd.nih.gov/researchFramework

Varas-Díaz, N., Rodríguez-Madera, S., Padilla, M., Rivera-Bustelo, K., Mercado-Ríos, C., Rivera-Custodio, J., Matiz-Reyes, A., Santiago-Santiago, A., González-Font, Y., Vertovec, J., Ramos-Pibernus, A., & Grove, K. (2023). On leaving: Coloniality and

physician migration in Puerto Rico. Social science & medicine (1982), 325, 115888. https://doi.org/10.1016/j.socscimed.2023.115888

Ver Hoef, J. M., & Boveng, P. L. (2007). Quasi-Poisson vs. negative binomial regression: how should we model overdispersed count data?. *Ecology,* 88(11), 2766–2772. https://doi.org/10.1890/07-0043.1

Wallington, S. F., & Feger, C. (2025). Then, Now, Next: Unpacking the Shifting Trajectory of Social Determinants of Health. International journal of environmental research and public health, 22(10), 1541. https://doi.org/10.3390/ijerph22101541

United States Census Bureau QuickFacts. (n.d.). U.S. Census Bureau QuickFacts: Puerto Rico. Census Bureau QuickFacts. https://www.census.gov/quickfacts/fact/table/PR/PST045224

World Health Organization. (n.d.). Social determinants of health. https://www.who.int/health-topics/social-determinants-of-health

Wu, S., Wang, R., Zhao, Y., Ma, X., Wu, M., Yan, X., & He, J. (2013). The relationship between self-rated health and objective health status: A population-based study. *BMC Public Health*, *13*, 320. https://doi.org/10.1186/1471-2458-13-

# Chapter II

## Más Allá de las Circunstancias: Social Determinants of Health and Self-Rated, Physical, and Mental Health Among Puerto Rican Adults

## Abstract

**Background.** Puerto Rico faces complex health challenges shaped by social, economic, and structural determinants. While self-rated health (SRH) is a well-validated predictor of morbidity and mortality, few studies have examined how multiple social determinants of health (SDOH) simultaneously correlate with SRH, physical health, and mental health among Puerto Rican adults.

**Methods.** Data were drawn from the 2023 Behavioral Risk Factor Surveillance System (BRFSS) for adults aged 18 or older living in Puerto Rico (n=4,594). Ten SDOH indicators—including life satisfaction, emotional support, social isolation, employment loss, food assistance, unmet material needs, transportation barriers, and stress—were analyzed. Binary logistic regression was used for SRH, and quasi-Poisson regression for count-based physical and mental health outcomes, adjusting for participant demographics.

**Results.** Life dissatisfaction and transportation barriers were consistently associated with poorer SRH and more physically unhealthy days, while stress was the strongest predictor of poor mental health. Associations with other SDOH (e.g., food assistance, employment loss) varied after adjustment for sociodemographics. Income and education were also significant correlates of all three health outcomes, highlighting broader socioeconomic influences on health perceptions and experiences.

**Conclusion.** Our findings highlight the need for public health interventions that address upstream SDOHs, particularly in contexts with unique sociopolitical and environmental vulnerabilities. Future research should further explore cultural and contextual factors affecting SRH in Puerto Rico to inform targeted, equity-oriented health strategies.

## Introduction

Puerto Rico faces a complex interaction of health determinants that extend far beyond risk associated with individual biological vulnerability to disease or challenges associated with healthcare access. These factors, known as the social determinants of health (SDOH), encompass non-medical influences such as income, education, occupation, and social relationships that critically shape individual and population health outcomes (Franks et al., 2003; Kawachi et al., 1999; Murata et al., 2006; Prus, 2011; Szwarcwald et al., 2005). The World Health Organization defines SDOH as the conditions in which people are born, grow, live, work, and age—as well as the broader forces and systems that shape those conditions—including socioeconomic policies, political structures, and social norms ("Social Determinants of Health," n.d.). Understanding these determinants is central to addressing inequities in health outcomes, as growing evidence demonstrates that social and structural conditions often exert a stronger influence on population health than medical care itself. The present study sought to address a critical population gap by investigating how various indicators of SDOH relate to subjective health assessments among Puerto Ricans living on the island.

### Conceptual Framework

This study is guided by the National Institute on Minority Health and Health Disparities (NIMHD) Research Framework, which conceptualizes health outcomes as products of interrelated factors operating across multiple domains and levels of influence (National Institute on Minority Health and Health Disparities, 2025). The framework delineates domains of influence—including biological, behavioral, physical/built environment, sociocultural environment, and the healthcare system—each interacting across individual, interpersonal, community, and societal levels. Within this multilevel structure, determinants can be understood

as operating along a continuum from upstream to downstream influences. Upstream determinants refer to broader structural and societal forces—such as economic stability, public policy, colonial legacies, and systemic inequities—that shape social and environmental conditions, whereas downstream determinants reflect the individual health perceptions and outcomes that emerge from these broader contexts (McMahon, 2022). Utilizing this model enables a holistic lens through which to analyze the intersections between social context and health among Puerto Ricans, while also aligning the study with federal minority health research priorities.

Complementing the NIMHD framework, this study also draws on syndemic theory to conceptualize how multiple, co-occurring adversities synergistically undermine health among Puerto Ricans (Singer et al., 2017). Syndemics occur when biological, social, and environmental epidemics interact within populations sharing common structural vulnerabilities, producing worse health outcomes than each factor alone (Singer et al., 2017). In Puerto Rico, potential syndemic conditions include chronic disease clusters (e.g., diabetes, cardiovascular disease), economic stressors (poverty, unemployment), and environmental threats (hurricanes, infrastructure failure), all worsened by colonial governance structures (Lafarga Previdi & Vélez Vega, 2020; Martin & Pace, 2025; McSorley et al., 2024). This theoretical lens illuminates how SDOH may not only independently predict self-rated health (SRH) but also interact synergistically to create compounded health burdens, providing a better understanding of health disparities on the island.

**SDOH and Related Outcomes**

SDOH provides a conceptual foundation for understanding SRH—a subjective but well-validated measure of perceived health widely used in public health research. Typically assessed using the single item, "In general, would you say your health is excellent, very good, good, fair,

or poor?" (Wu et al., 2013), SRH captures individuals' comprehensive evaluations of their health status. In addition to global SRH, researchers often examine domain-specific indicators such as self-rated physical health and self-rated mental health, which represent more focused assessments of these individual dimensions of perceived health. Despite its apparent simplicity, SRH has proven to be one of the most consistent and powerful predictors of morbidity, functional decline, and mortality across diverse populations (Bombak, 2013; Idler & Kasl, 1991; Murata et al., 2006). Researchers propose that SRH reflects a synthesis of multiple health domains—physical conditions, psychological well-being, and social functioning—and may even capture early physiological or symptomatic signals not yet identified in medical assessments (Hamplová et al., 2022; Cho et al., 2022). Furthermore, behavioral and psychosocial factors such as chronic stress, depressive symptoms, coping strategies, and lifestyle behaviors (e.g., smoking, sleep, and diet) are significant predictors of SRH (Hanmer, 2021). Because SRH integrates diverse health dimensions and requires minimal resources to assess, it is particularly valuable in surveillance efforts and in understanding health disparities within marginalized or resource-limited populations.

Globally, SRH research has demonstrated consistent social patterning, with socioeconomic status, education, gender, and social cohesion emerging as dominant predictors (Franks et al., 2003; Kawachi et al., 1999; Prus, 2011). Studies have found, for instance, that lower income and limited social support are strongly associated with poorer SRH ratings and increased risk of adverse health outcomes (Szwarcwald et al., 2005; Idler & Kasl, 1991). Variations in SRH among regions and populations highlight how social and structural contexts shape how individuals internalize and evaluate their health. However, there is little research examining these associations within territories in the United States (U.S.) such as Puerto Rico,

where historical and economic conditions differ substantially from the mainland and have profound effects on health systems and outcomes.

**SDOH in Puerto Rico**

Puerto Rico's public health context is shaped by longstanding structural determinants that intersect with its sociopolitical history. The island faces persistent socioeconomic disparities and widespread barriers to medical care, including physician shortages, limited healthcare coverage, and geographic disparities in access (Frontera-Escudero et al., 2023). Educational attainment and employment opportunities are also behind national averages, and environmental vulnerabilities are compounded by aging infrastructure (Frontera-Escudero et al., 2023). These conditions reflect not only material inequities but also the legacy of colonial governance and fiscal dependence that have constrained public investment in health and social systems (Martin & Pace, 2025; McSorley et al., 2024). The compounded effects of recurring natural disasters, such as Hurricanes Maria and Irma, subsequent earthquakes, and the COVID-19 pandemic, have further magnified inequities by disrupting healthcare services, displacing residents, and straining recovery efforts (Lafarga Previdi & Vélez Vega, 2020). Together, these structural and environmental stressors create a context in which SDOH may play a large role in shaping perceived health.

While prior studies have explored certain SDOH—such as income inequality, food insecurity, or access to care—in Puerto Rican or broader Latinx populations, very few have focused on how these factors influence SRH specifically within Puerto Rico (Frontera-Escudero et al., 2023). Furthermore, comparative findings from the mainland U.S. may not translate directly due to distinct cultural values, healthcare infrastructure, and social safety nets on the island. This gap in understanding limits the ability of policymakers and public health

practitioners to design nuanced, equity-focused interventions responsive to Puerto Rico's unique social and political realities. Taken together, these factors point to a critical problem: despite substantial evidence that SDOH shape SRH and can predict morbidity and mortality, little is known about how these determinants influence various aspects of SRH among Puerto Ricans living on the island.

### The Present Study

The present study addresses a critical population gap by investigating how various indicators of SDOH relate to subjective health assessments among Puerto Ricans living on the island. Specifically, the study's primary aim was to determine the associations between SDOH indicators (e.g., income, education, employment, social support, and neighborhood context) and overall SRH. The secondary aim was to assess how these same determinants correlate with domain-specific measures—self-rated physical health and self-rated mental health. Given existing evidence that favorable social conditions promote better health perceptions, we hypothesize that higher levels of education, income, and social integration will be positively associated with higher SRH ratings. Conversely, social and economic disadvantages were expected to correspond with poorer self-rated health. Information on potential associations between SDOH and health outcomes within this population could provide valuable public health insight regarding pathways through which social and structural inequities may influence perceived health among Puerto Ricans, and inform strategies for context-specific, equity-driven interventions.

## Methods

### Data Source

Data for the present study were from the 2023 Behavioral Risk Factor Surveillance System (BRFSS), which collected data through state-specific health survey systems among adults 18 years or older residing in the U.S., the U.S. Virgin Islands, the District of Columbia, Puerto Rico, and Guam (*CDC*, 2024). The survey collects information on health risk behaviors, preventive health practices, and healthcare access, focusing primarily on chronic diseases and injuries (CDC, 2024). Additionally, the survey collected data on emerging health issues such as vaccine shortages, influenza, and similar illnesses (CDC, 2024). The questionnaire was administered via computer-assisted telephone interviewing (CATI) from July to December 2023. Participants were recruited through random-digit dialing of landlines and cellular phones to ensure broad coverage. Verbal informed consent was obtained, and participants were informed that involvement was voluntary, confidential, and that they could stop at any time. The University of Tennessee, Knoxville Institutional Review Board approved analyses of the extant data as being non-human subjects research.

## Measures

### *Demographics*

Participants provided information on age, sex, race/ethnicity, household income, educational attainment, and marital status. Age was grouped into six categories: 18–24, 25–34, 35–44, 45–54, 55–64, and 65 years or older. Sex was coded as male or female. Race and ethnicity were self-identified and categorized as White, Black or African American, Hispanic or Latino, Asian, Native Hawaiian or Other Pacific Islander, American Indian or Alaska Native, mixed race, or other. Annual household income was reported in seven brackets: less than $15,000; $15,000 to less than $25,000; $25,000 to less than $35,000; $35,000 to less than $50,000; $50,000 to less than $100,000; $100,000 to less than $200,000; and $200,000 or more.

Educational attainment was assessed as less than a high school diploma, high school graduate or equivalent, some college or technical education, and completion of a college or technical degree. Marital status was reported in six categories: married, divorced, widowed, separated, never married, and a member of an unmarried couple.

**SDOH**

SDOH were assessed using ten indicators capturing exposure to social stressors and structural vulnerabilities. The dichotomous indicators (0 = *no*, 1 = *yes*) were utilized to assess SDOH, encompassing dimensions of social connection, economic stability, and unmet material needs. These included: satisfaction with life, emotional support, social isolation, loss or reduction of employment, receiving food stamps in the past 12 months, food not lasting or insufficient funds to buy more in the past 12 months, inability to pay bills or utility bills, lack of reliable transportation, and experiencing stress within the last 30 days. Collectively, these measures represent multiple dimensions of social vulnerability, including economic instability, social disconnection, and unmet material and access-related needs.

**Self-Rated Health**

Three primary outcomes were examined: overall self-rated health, self-rated number of physically unhealthy days, and self-rated number of mentally unhealthy days, each assessed over the past 30 days. Self-rated general health was measured using a single item categorizing respondents' health as excellent, very good, good, fair, or poor. Physical and mental health were assessed through items asking respondents to report the number of days in the past 30 days when their physical or mental health was "not good," respectively. These measures are widely used indicators of health status and well-being in population-based research (Bombak, 2013; Idler & Kasl, 1991; Murata et al., 2006; Wu et al., 2013).

**Analytic Plan**

All analyses were conducted in R (version 4.5.0; R Core Team, 2025) and R Studio (version 2024.12.1+563; R Studio Team, 2024) using mice (van Buuren & Groothuis-Oudshoorn, 2011), psych (Revelle, 2024), furniture (Barrett, 2023), tidyverse (Wickham et al., 2019), and corrplot (Wei & Simko, 2023) packages. Across all study variables, 3.0% of responses were missing. Missingness was highest for SDOH variables, particularly employment status (8.9%), life satisfaction (2.8%), emotional support (2.6%), and loneliness (2.4%). The pattern of missingness was significantly related to variables of interest, with respondents reporting higher risk categories for SDOH and outcome variables being largely more likely to have missing data. As such, data were treated as being Missing Not at Random (MNAR). Multiple imputation was performed using the random forest algorithm. Due to preliminary analysis indicating skewness in the survey responses, all ten SDOH items were re-coded as binary variables in which positive answers—such as always or usually—and negative answers — such as sometimes, rarely, or never—were grouped together. Self-rated general health was re-coded as a binary variable in which positive answers and negative answers were grouped together (0 = fair/poor and 1 = excellent/very good/good).

Five covariates were included in the analyses: sex of respondent, marital status, education, income, and age. To address the right-skewed distribution of the income variable observed in the preliminary analysis, this variable was re-coded into a binary variable based on the 2023 median income in Puerto Rico (< $25,000 and ≥ $25,000) (*Census Bureau Table*). Similarly, the six-level age variable was reduced to three levels: (1) Age 18 through 34 (n=918), (2) Age 35 to 54 (n=1520), and (3) Age 55 and older (n=2156). This adjustment was made due to the relatively lower number of survey respondents in the younger age categories, allowing for a

more representative comparison between groups. The original marital status categories were consolidated from six to four options: (1) married, (2) divorced, widowed, and/or separated, (3) never married, and (4) a member of an unmarried couple. This consolidation was necessary due to the lower response rates for the divorced (n=618), widowed (n=411), and separated (n=164) categories compared to the married (n=1,714) and never married (n=1,160) categories, along with the similar contextual factors these statuses represent. Despite the relatively low response rate for the "member of an unmarried couple" category (n=504), it was retained as a distinct category due to its different implications from being divorced, widowed, or separated. Race and ethnicity were not included in this analysis, as over 99% of the survey respondents residing in Puerto Rico were Hispanic.

To address our primary objective, binary logistic regressions with 95% confidence intervals (CIs) were conducted to examine associations between SDOH and self-rated general health, yielding odds ratios that account for potential confounding. Model assumptions were tested and met. For our secondary objectives, quasi-Poisson regressions were used to examine SDOH associations with self-rated physical and mental health, which are count outcomes. Regression outputs provide log-scale coefficients (β), but results are exponentiated and reported as incidence rate ratios (IRR) with 95% CIs to facilitate interpretation of how predictors relate to the frequency of poor health days. Overdispersion violated Poisson assumptions and was addressed with quasi-Poisson models (ver Hoef & Boveng, 2007).

## Results

### Descriptives

Table 1.1 presents descriptive statistics for the selected indicators, outcomes, and covariates based on the imputed sample. Participants were predominantly female (62.5%; *n* =

2,872), with 46.9% aged 55 years or older (*n* = 2,156), 33.1% aged 35-54 years (*n* = 1,520), and 20.0% aged 18-34 years (*n* = 918). Household income showed 53.3% (*n* = 2,447) of participants earned less than $25,000 annually and 46.7% (*n* = 2,147) greater than $25,000. Participants reported their educational attainment as attending college/technical school (37.3%; *n* = 1,715), some college/technical school (26.8%; *n* = 1,231), high school (24.7%; *n* = 1,135), and less than high school (11.2%; *n* = 513). Marital status reflected 37.5% married (*n* = 1,723), 26.0% divorced/widowed/separated (*n* = 1,196), 25.4% never married (*n* = 1,167), and 11.1% unmarried couples (*n* = 508). SRH was dichotomized as good/excellent/very good/good (67.1%; *n* = 3,081) versus fair/poor (32.9%; *n* = 1,513). Mean poor physical health days (past 30) were 14.5 (SD = 11.1); poor mental health days averaged 15.7 (SD = 11.0). SDOH risk prevalence showed employment difficulties (10.4%; n = 476), food stamp usage (44.4%; *n* = 2,039), food insecurity (22.1%; *n* = 1,013), and loneliness (35.4%; *n* = 1,624). Unimputed descriptives are presented in Supplemental Table 1.1.

**Social Determinants of Health and Self-Rated Health**

In unadjusted analyses (see Table 1.2), several SDOH indicators were significantly associated with self-rated health. Individuals who reported dissatisfaction with their life had substantially lower odds of reporting excellent/very good/good SRH compared with those who were satisfied (OR = 0.26, 95% CI: 0.17–0.40, p < .001). Similarly, individuals who reported limited emotional support had lower odds of excellent/very good/good SRH (OR = 0.74, 95% CI: 0.58–0.95, p = .017). Experiences of loneliness were also significantly associated with fair/poor SRH, with individuals reporting loneliness having lower odds of reporting excellent/very good/good SRH (OR = 0.60, 95% CI: 0.49–0.73, p < .001). Employment-related hardship demonstrated a strong association with SRH in the unadjusted model. Individuals

reporting employment instability had significantly lower odds of reporting excellent/very good/good SRH compared with those who did not report employment hardship (OR = 0.46, 95% CI: 0.33–0.63, p < .001). Indicators related to food access were also significant. Individuals who received food assistance had lower odds of reporting excellent/very good/good SRH (OR = 0.43, 95% CI: 0.36–0.53, p < .001), and individuals experiencing food insecurity similarly had lower odds of excellent/very good/good SRH (OR = 0.69, 95% CI: 0.55–0.88, p = .002). Transportation barriers were significantly associated with fair/poor SRH (OR = 0.49, 95% CI: 0.36–0.66, $p < .001$), as was frequent stress (OR = 0.73, 95% CI: 0.58–0.93, $p = .009$). In contrast, difficulty paying bills (OR = 0.99, 95% CI: 0.75–1.29, $p = .925$) and threatened utility loss (OR = 0.96, 95% CI: 0.67–1.35, $p = .800$) were not significantly associated with SRH in the unadjusted models.

After adjusting for sociodemographic characteristics (see Table 1.2), several SDOH indicators remained significantly associated with SRH. Individuals who reported life dissatisfaction had significantly lower odds of reporting excellent/very good/good SRH compared with those who were satisfied (OR = 0.23, 95% CI: 0.15–0.36, p < .001). Limited emotional support remained significantly associated with lower odds of excellent/very good/good SRH, although the magnitude of the association was modest (OR = 0.76, 95% CI: 0.58–0.99, p = .045). Loneliness also remained significantly associated with fair/poor SRH (OR = 0.58, 95% CI: 0.47–0.73, p < .001). Food-related indicators remained significant in the adjusted model. Individuals who received food assistance had lower odds of reporting excellent/very good/good SRH (OR = 0.71, 95% CI: 0.56–0.91, p = .006), and those who experienced food insecurity had reduced odds of reporting excellent/very good/good SRH (OR = 0.72, 95% CI: 0.55–0.93, p = .013). Transportation barriers demonstrated one of the strongest

associations among the SDOH indicators, with individuals who reported transportation problems having 56% lower odds of reporting excellent/very good/good SRH (OR = 0.44, 95% CI: 0.32–0.62, p < .001). Frequent stress was also significantly associated with lower odds of excellent/very good/good SRH (OR = 0.52, 95% CI: 0.40–0.68, p < .001). Employment hardship was no longer statistically significant after adjustment for demographic characteristics (OR = 1.34, 95% CI: 0.94–1.91, p = .101). Similarly, difficulty paying bills (OR = 0.86, 95% CI: 0.63–1.17, p = .340) and threatened utility loss (OR = 0.91, 95% CI: 0.61–1.35, p = .627) were not significantly associated with SRH in the adjusted model.

Among sociodemographic covariates, age was significantly associated with SRH. Compared with adults aged 18–34 years, individuals aged 35–54 had lower odds of reporting excellent/very good/good SRH (OR = 0.47, 95% CI: 0.33–0.66, p < .001), and those aged 55 years and older had substantially lower odds of reporting excellent/very good/good SRH (OR = 0.17, 95% CI: 0.12–0.24, p < .001). Income was also significantly associated with SRH, with individuals who reported household incomes greater than $25,000 having higher odds of reporting excellent/very good/good SRH compared with those with incomes lower than $25,000 (OR = 1.37, 95% CI: 1.07–1.75, p = .013). Educational attainment demonstrated a graded association with SRH. Compared with individuals with less than a high school education, those with some college or technical training had higher odds of reporting excellent/very good/good SRH (OR = 1.66, 95% CI: 1.18–2.35, p = .004), and those with a college or technical degree had the highest odds of reporting excellent/very good/good SRH excellent/very good/good SRH (OR = 2.22, 95% CI: 1.59–3.09, p < .001). Sex and marital status were not significantly associated with self-rated general health. Overall, several SDOH indicators—including life dissatisfaction, limited emotional support, loneliness, food insecurity, transportation barriers, and stress—were

significantly associated with lower odds of reporting excellent/very good/good SRH, even after adjustment for sociodemographic characteristics.

**Social Determinants of Health and Self-Rated Number of Physically Unhealthy Days**

In unadjusted analyses (see Table 1.2), several SDOH indicators were associated with the number of days respondents reported their physical health was not good. Individuals who reported life dissatisfaction had endorsed significantly more days of poor physical health compared with those who were satisfied with life (IRR = 1.22, 95% CI: 1.06–1.42, $p$ = .007). Similarly, individuals who received food assistance reported more unhealthy days of physical health (IRR = 1.14, 95% CI: 1.03–1.25, $p$ = .011). Transportation barriers were also significantly associated with more endorsed days of unhealthy physical health, with respondents who reported transportation difficulties experiencing more days of unhealthy physical health (IRR = 1.22, 95% CI: 1.07–1.38, $p$ = .002). Other SDOH indicators, including emotional support, loneliness, employment hardship, food insecurity, difficulty paying bills, threatened utility loss, and stress, were not significantly associated with the number of days of unhealthy physical health in the unadjusted models.

After adjusting for sociodemographic characteristics (see Table 1.2), life dissatisfaction remained significantly associated with poorer physical health. Respondents who reported dissatisfaction with life experienced more days of poor physical health compared with those who were satisfied (IRR = 1.17, 95% CI: 1.01–1.35, p = .032). Transportation barriers also remained significant, with individuals reported transportation difficulties experiencing more days of poor physical health (IRR = 1.21, 95% CI: 1.07–1.36, p = .002). In addition, frequent stress was associated with a greater number of days of poor physical health (IRR = 1.12, 95% CI: 1.00–1.24, p = .046).

Among sociodemographic variables, older age was associated with greater endorsed days of unhealthy physical health. Compared with adults aged 18–34 years, individuals aged 55 years and older reported significantly more days of poor physical health (IRR = 1.53, 95% CI: 1.26–1.85, p < .001). Income was also significantly associated with physical health, with individuals who reported household incomes greater than $25,000 experiencing fewer days of poor physical health compared with those with lower incomes (IRR = 0.78, 95% CI: 0.70–0.88, p < .001). Educational attainment was also associated with physical health, with individuals with a high school education reporting fewer days of poor physical health compared with those with less than a high school education (IRR = 0.86, 95% CI: 0.76–0.98, p = .026). Other SDOH indicators and sociodemographic variables were not significantly associated with days of unhealthy physical health in the adjusted model.

**Social Determinants of Health and Self-Rated Number of Mentally Unhealthy Days**

In unadjusted analyses (see Table 2), several SDOH indicators were associated with the number of days respondents reported their mental health was not good. Life dissatisfaction was associated with more days of poor mental health (IRR = 1.21, 95% CI: 1.07–1.36, $p = .002$). Individuals who received food assistance also reported more days of poor mental health (IRR = 1.19, 95% CI: 1.08–1.30, $p < .001$). The strongest association was observed for stress, with individuals who reported frequent stress experiencing substantially more days of poor mental health (IRR = 1.53, 95% CI: 1.39–1.70, $p < .001$). Other SDOH indicators, including emotional support, loneliness, employment hardship, food insecurity, financial strain, threatened utility loss, and transportation barriers, were not significantly associated with endorsed days of mentally unhealthy days in the unadjusted models.

After adjusting for sociodemographic characteristics (see Table 1.2), life dissatisfaction remained significantly associated with poorer mental health, with individuals who reported dissatisfaction experiencing more days of poor mental health (IRR = 1.21, 95% CI: 1.08–1.35, p < .001). Stress remained the strongest predictor of mental health, with individuals who reported frequent stress experiencing substantially more days of poor mental health compared with those reporting lower stress levels (IRR = 1.54, 95% CI: 1.40–1.70, p < .001).

Among sociodemographic variables, higher income was associated with fewer days of poor mental health. Individuals who reported household incomes greater than $25,000 experienced fewer days of poor mental health compared with those with lower incomes (IRR = 0.89, 95% CI: 0.80–1.00, p = .049). Educational attainment was also associated with mental health, with individuals with a high school education reporting fewer days of poor mental health compared with those with less than a high school education (IRR = 0.81, 95% CI: 0.71–0.92, p = .002). In addition, individuals who were divorced, widowed, or separated reported more days of poor mental health compared with married individuals (IRR = 1.15, 95% CI: 1.03–1.29, p = .013). Other SDOH indicators were not significantly associated with endorsed days of poor mental health in the adjusted model. Overall, transportation barriers, life dissatisfaction, and stress emerged as the most consistent SDOH indicators associated with poorer health outcomes, although patterns varied across self-rated, physical, and mental health measures.

## Discussion

The present study contributes to the growing literature examining the role of SDOH in shaping population health outcomes by simultaneously evaluating multiple domains of social and structural conditions across several health outcomes among Puerto Rican adults. While prior research has often examined individual determinants or specific health outcomes in isolation, this

present study considers a broader range of factors—including financial hardship, transportation barriers, social support, stress, and food assistance—within a single analytic framework. By assessing these determinants across self-rated health, and days of poor physical health and mental health outcomes, the study provides a more comprehensive understanding of how social conditions shape health among Puerto Rican populations. Additionally, this study contributes to practice by highlighting the importance of considering multiple dimensions of social context when addressing population health disparities. These findings reinforce the need for public health strategies that extend beyond traditional health care delivery and instead address social and structural conditions that may shape everyday health experiences.

Several SDOH indicators were consistently associated with health outcomes across models. Dissatisfaction with life and transportation barriers were among the most consistent predictors of poorer health outcomes, while stress emerged as the strongest predictor of poor mental health. These findings align with a growing body of literature demonstrating that psychosocial and structural factors are also important correlates of both perceived and experienced health outcomes among Puerto Rican adults (Hamplová et al., 2022; Cho et al., 2022; Hanmer, 2021). Life dissatisfaction was associated with poorer SRH as well as increased days of poor physical and mental health among Puerto Rican adults. This finding is consistent with prior research suggesting that subjective well-being is strongly linked to health perceptions and health-related quality of life (Szwarcwald et al., 2005; Idler & Kasl, 1991). Life satisfaction has been shown to capture broader aspects of social stability, emotional well-being, and perceived life circumstances that correlate with overall health assessments.

Transportation barriers also emerged as an important determinant of health outcomes. Individuals reporting transportation challenges were significantly less likely to report good self-

rated health and experienced more days of poor physical health. Transportation barriers have been widely documented as a SDOH that can limit access to health care services, employment opportunities, and social resources, and can ultimately contribute to poorer health outcomes (Wolfe et al., 2020). Stress was the most strongly associated determinant of mental health outcomes. Individuals who reported frequent stress experienced substantially more days of poor mental health compared with those reporting lower levels of stress. This finding aligns with extensive literature demonstrating the negative effects of chronic stress on psychological well-being (Schneiderman et al., 2005). In the Puerto Rican context, persistent economic instability, disaster recovery, and structural inequalities may further worsen chronic stress exposure among residents (Frontera-Escudero et al., 2023).

Other determinants, such as food assistance participation and food insecurity, showed associations in some models but were not consistently significant after adjusting for sociodemographic characteristics. This pattern may reflect the interconnected nature of socioeconomic disadvantages, where food insecurity often co-occurs with broader economic constraints such as low income, unemployment, and limited educational opportunities among Puerto Rican adults (Lafarga Previdi & Vélez Vega, 2020; Martin & Pace, 2025; McSorley et al., 2024). As a result, the independent effects of food-related indicators may become reduced when these related socioeconomic factors are included in the model.

**Implications**

The findings of this study have important implications for public health policy and practice in Puerto Rico. The consistent role of transportation barriers highlights the importance of addressing structural challenges related to mobility and access to services. In many areas of Puerto Rico, limited public transportation infrastructure and geographic barriers can make it

difficult for residents to access health care services, employment opportunities, and other essential resources (Martin & Pace, 2025; McSorley et al., 2024). Efforts to improve transportation infrastructure and access could represent an important strategy for improving population health

The strong association between stress and mental health outcomes also highlights the need for expanded mental health services and community-based interventions that address psychosocial stressors. Puerto Rico has experienced numerous economic and environmental challenges in recent years, including economic instability, natural disasters, and public health crises, all of which may contribute to chronic stress among residents (Frontera-Escudero et al., 2023). Public health interventions that promote resilience, social support, and mental health care access may therefore play an important role in improving mental health outcomes. Additionally, the association between income and health outcomes suggests that broader socioeconomic policies aimed at reducing poverty and improving economic stability may also have meaningful health benefits. Addressing economic hardship and improving educational opportunities may represent key pathways for reducing health disparities within the Puerto Rican population (Lafarga Previdi & Vélez Vega, 2020).

**Limitations**

Several limitations should be considered when interpreting the findings of this study. First, data were cross-sectional, which limited the ability to establish temporal ordering and causal relationships between SDOH and health outcomes. Thus, findings should be viewed as correlates instead of predictors of health outcomes. Second, the measures used in the present study are based on self-reported survey data, which may be subject to recall or social desirability bias. Self-rated health and reported days of poor health and mental health may also be influenced

by individual perceptions and cultural interpretations of health (Choi & Miyamoto, 2022). Third, the SDOH variables included in this analysis capture only a subset of the broader social and structural factors that may influence health outcomes. Other important determinants, such as neighborhood-level conditions, environmental exposures, and access to health care services, were not directly measured in the dataset. Fourth, because BRFSS is conducted via telephone survey, adults without access to either a landline or cell phone may be underrepresented, potentially excluding lower-income households and affecting representativeness. Finally, although this study focuses on Puerto Rican adults, the findings may not be generalizable to all Puerto Rican communities, particularly those living outside of Puerto Rico or in different sociopolitical contexts.

**Conclusion**

This present study contributes to the growing literature on SDOH by demonstrating how multiple social and structural conditions are associated with SRH and health-related quality of life among Puerto Ricans living on the island. The findings highlight the importance of socioeconomic stability, food security, and psychosocial stressors in potentially shaping health perceptions, underscoring the broader role of structural and social contexts in population health. These results support prior research demonstrating that social and economic disadvantage is closely tied to poorer health outcomes and reinforce the need for policies and interventions that address upstream determinants of health.

At the same time, because SRH has not been extensively studied in Puerto Rico, the extent to which cultural and social factors influence how individuals perceive and report their health remains unclear. Future research should further examine how these contextual and cultural influences shape self-rated health among Puerto Ricans and how these perceptions align with

objective health indicators. Understanding whether discrepancies exist between perceived and measured health will be important for determining the extent to which self-rated health can reliably serve as a population health indicator in Puerto Rico. Clarifying these relationships will ultimately help guide more accurate health surveillance and the development of culturally and contextually responsive public health interventions for Puerto Ricans living on the island.

## References


Bombak, A. E. (2013). Self-rated health and public health: A critical perspective. *Frontiers in Public Health*, *1*, 15. https://doi.org/10.3389/fpubh.2013.00015

Centers for Disease Control and Prevention. (2024, February 9). Behavioral Risk Factor Surveillance System (BRFSS). U.S. Department of Health and Human Services. https://www.cdc.gov/brfss/index.html

Cho, H., Wang, Z., Yabroff, K. R., Liu, B., McNeel, T., Feuer, E. J., & Mariotto, A. B. (2022). Estimating life expectancy adjusted by self-rated health status in the United States: National health interview survey linked to the mortality. *BMC Public Health*, *22*(1), 141. https://doi.org/10.1186/s12889-021-12332-0

Choi, J. H., & Miyamoto, Y. (2022). Cultural differences in self-rated health: The role of influence and adjustment. *Japanese Psychological Research*, *64*(2), 156–169. https://doi.org/10.1111/jpr.12405

Franks, P., Gold, M. R., & Fiscella, K. (2003). Sociodemographics, self-rated health, and mortality in the US. *Social Science & Medicine (1982)*, *56*(12), 2505–2514. https://doi.org/10.1016/s0277-9536(02)00281-2

Frontera-Escudero, I., Bartolomei, J. A., Rodríguez-Putnam, A., & Claudio, L. (2023). Sociodemographic and health risk factors associated with health-related quality of life among adults living in Puerto Rico in 2019: A cross-sectional study. *BMC Public Health*, *23*(1), 2150. https://doi.org/10.1186/s12889-023-17115-3

Hamplová, D., Klusáček, J., & Mráček, T. (2022). Assessment of self-rated health: The relative importance of physiological, mental, and socioeconomic factors. *PLOS ONE*, *17*(4), e0267115. https://doi.org/10.1371/journal.pone.0267115

Hanmer, J. (2021). Measuring population health: Association of self-rated health and PROMIS measures with social determinants of health in a cross-sectional survey of the US population. *Health and Quality of Life Outcomes*, *19*(1), 221. https://doi.org/10.1186/s12955-021-01854-1

Idler, E. L., & Kasl, S. (1991). Health perceptions and survival: Do global evaluations of health status really predict mortality? *Journal of Gerontology*, *46*(2), S55–S65. https://doi.org/10.1093/geronj/46.2.S55

Kawachi, I., Kennedy, B. P., & Glass, R. (1999). Social capital and self-rated health: A contextual analysis. *American Journal of Public Health*, *89*(8), 1187–1193. https://doi.org/10.2105/ajph.89.8.1187

Lafarga Previdi, I., & Vélez Vega, C. M. (2020). Health disparities research framework adaptation to reflect Puerto Rico's socio-cultural context. *International Journal of Environmental Research and Public Healt*h, 17(22), 8544. https://doi.org/10.3390/ijerph17228544

Martin, J. N., & Pace, T. W. W. (2025). Colonialism as a social determinant of health in Puerto Rico: Using the socioecological model to examine how the Jones act impacted health after hurricane María. *Journal of Transcultural Nursing: Official journal of the Transcultural Nursing Society*, 36(1), 8–15. https://doi.org/10.1177/10436596241274123

McMahon N. E. (2022). Framing action to reduce health inequalities: what is argued for through use of the 'upstream-downstream' metaphor?. Journal of public health (Oxford, England), 44(3), 671–678. https://doi.org/10.1093/pubmed/fdab157

McSorley, A. M., Rivera-González, A. C., Mercado, D. L., Pagán, J. A., Purtle, J., & Ortega, A. N. (2024). United States federal policies contributing to health and health care

inequities in Puerto Rico. *American Journal of Public Health*, 114(S6), S478–S484. https://doi.org/10.2105/AJPH.2024.307585

Murata, C., Kondo, T., Tamakoshi, K., Yatsuya, H., & Toyoshima, H. (2006). Determinants of self-rated health: Could health status explain the association between self-rated health and mortality? *Archives of Gerontology and Geriatrics*, *43*(3), 369–380. https://doi.org/10.1016/j.archger.2006.01.002

National Institute on Minority Health and Health Disparities (2025). NIMHD Research Framework. Retrieved from https://nimhd.nih.gov/researchFramework

Prus, S. G. (2011). Comparing social determinants of self-rated health across the United States and Canada. *Social Science & Medicine*, *73*(1), 50–59. https://doi.org/10.1016/j.socscimed.2011.04.010

Revelle, W. (2024). psych: Procedures for personality and psychological research (Version 2.4.1). Northwestern University. https://CRAN.R-project.org/package=psych

*S1901: Income in the Past 12 Months ... - Census Bureau Table*. (n.d.). Retrieved June 24, 2024, from https://data.census.gov/table/ACSST1Y2022.S1901?g=040XX00US72

Singer, M., Bulled, N., Ostrach, B., & Mendenhall, E. (2017). Syndemics and the biosocial conception of health. *Lancet*, 389(10072), 941–950. https://doi.org/10.1016/S0140-6736(17)30003-X

Schneiderman, N., Ironson, G., & Siegel, S. D. (2005). Stress and health: Psychological, behavioral, and biological determinants. *Annual Review of Clinical Psychology*, 1, 607–628. https://doi.org/10.1146/annurev.clinpsy.1.102803.144141

*Social determinants of health*. (n.d.). World Health Organization. Retrieved March 25, 2024, from https://www.who.int/health-topics/social-determinants-of-health

Szwarcwald, C. L., Souza-Júnior, P. R. B. de, Esteves, M. A. P., Damacena, G. N., & Viacava, F. (2005). Socio-demographic determinants of self-rated health in Brazil. *Cadernos De Saude Publica*, *21 Suppl*, 54–64. https://doi.org/10.1590/s0102-311x2005000700007

van Buuren, S., & Groothuis-Oudshoorn, K. (2011). mice: Multivariate imputation by chained equations in R. *Journal of Statistical Software,* 45(3), 1–67. https://doi.org/10.18637/jss.v045.i03

ver Hoef, J. M., & Boveng, P. L. (2007). Quasi-Poisson vs. negative binomial regression: how should we model overdispersed count data?. *Ecology,* 88(11), 2766–2772. https://doi.org/10.1890/07-0043.1

Wei T, Simko V (2024). R package 'corrplot': Visualization of a Correlation Matrix. (Version 0.95), https://github.com/taiyun/corrplot

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., ... & Yutani, H. (2019). Welcome to the tidyverse. *Journal of Open Source Software*, 4(43), 1686. https://doi.org/10.21105/joss.01686

Wolfe, M. K., McDonald, N. C., & Holmes, G. M. (2020). Transportation barriers to health care in the United States: Findings from the national health interview survey, 1997-2017. *American Journal of Public Health*, 110(6), 815–822. https://doi.org/10.2105/AJPH.2020.305579

Wu, S., Wang, R., Zhao, Y., Ma, X., Wu, M., Yan, X., & He, J. (2013). The relationship between self-rated health and objective health status: A population-based study. *BMC Public Health*, *13*, 320. https://doi.org/10.1186/1471-2458-13-

## Appendix

## Tables

**Table 1.1** Imputed Demographic and SDOH Characteristics of the Sample (n = 4,594)

| Variable | Category | n (%) / Mean (SD) |
|---|---|---|
| Age (years) | 18-34 | 918 (20.0) |
| | 35-54 | 1520 (33.1) |
| | 55+ | 2156 (46.9) |
| Income | < $25,000 | 2447 (53.3%) |
| | ≥ $25,000 | 2147 (46.75%) |
| Sex | Male | 1722 (37.5%) |
| | Female | 2872 (62.5%) |
| Education | < High school | 513 (11.2) |
| | High school | 1135 (24.7%) |
| | Some college/Technical school | 1231 (26.8%) |
| | College/Technical school | 1715 (37.3%) |
| Marital Status | Married | 1723 (37.5%) |
| | Divorced/Widowed/Separated | 1196 (26.0%) |
| | Never married | 1167 (25.4%) |
| | Unmarried couple | 508 (11.1%) |
| Life Satisfaction | Satisfied/Very satisfied | 4389 (95.5%) |
| | Dissatisfied/Very dissatisfied | 205 (4.5%) |
| Emotional Support | Always/Usually | 3809 (82.9%) |
| | Sometimes/Rarely/Never | 785 (17.1%) |
| Loneliness | Rarely/Never | 2970 (64.6%) |
| | Always/Usually/Sometimes | 1624 (35.4%) |
| Reduced Employment (Hours) | No | 4118 (89.6%) |
| | Yes | 476 (10.4%) |
| Food Stamp Usage | No | 2555 (55.6%) |
| | Yes | 2039 (44.4%) |
| Food Insecurity | Rarely/Never | 3581 (77.9%) |
| | Always/Usually/Sometimes | 1013 (22.1%) |
| Difficulty Paying Bills | No | 3908 (85.1%) |
| | Yes | 686 (14.9%) |
| Difficulty Paying Utilities | No | 4229 (92.1%) |
| | Yes | 365 (7.9%) |
| Transportation Barriers | No | 4105 (89.4%) |
| | Yes | 489 (10.6%) |
| Stress (in past 30 days) | Sometimes/Rarely/Never | 3646 (79.4%) |

**Table 2.1** Imputed Demographic and SDOH Characteristics of the Sample (n = 4,594)

(Continued)

| | | |
|---|---|---|
| Self-Rated General Health | Always/Usually | 948 (20.6%) |
| | Fair/Poor | 1513 (32.9%) |
| | Good/Very Good/Excellent | 3081 (67.1%) |
| Self-Rated Physical Health (in past 30 days) | - | 14.5(11.1) |
| Self-Rated Mental Health (in past 30 days) | - | 15.7(11.0) |

**Table 1.2** Associations Between Social Determinants of Health and Self-Reported General, Physical, and Mental Health Among Puerto Rican Adults (n = 4,594)

| | Self-Reported General Health OR [95% CI] | | Self-Reported Physical Health Exp(β) [95% CI] | | Self-Reported Mental Health Exp(β) [95% CI] | |
|---|---|---|---|---|---|---|
| Independent Variable | Model I | Model II | Model I | Model II | Model I | Model II |
| Life dissatisfaction | 0.26 [0.17-0.40]** | 0.23 [0.15-0.36]** | 1.22 [1.06-1.42]* | 1.17 [1.01-1.35]* | 1.21 [1.07-1.36]* | 1.21 [1.08-1.35]* |
| Low emotional support | 0.74 [0.58-0.95]* | 0.76 [0.58-0.99]* | 1.02 [0.90-1.15] | 1.00 [0.89-1.12] | 0.99 [0.88-1.10]* | 0.98 [0.88-1.08]* |
| Loneliness | 0.60 [0.49-0.73]** | 0.58 [0.47-0.73]** | 1.10 [0.98-1.22] | 1.05 [0.96-1.16] | 1.07 [0.96-1.19] | 1.05 [0.94-1.16] |
| Employment loses | 2.19 [1.59-3.01]** | 1.34 [0.94-1.91] | 0.92 [0.79-1.08] | 1.10 [0.95-1.27] | 1.00 [0.89-1.14] | 1.09 [0.96-1.23] |
| Received food stamps | 0.43 [0.36-0.53]** | 0.71 [0.56-0.91]* | 1.14 [1.03-1.25]* | 0.98 [0.89-1.09] | 1.19 [1.08-1.30]** | 1.07 [0.97-1.18] |
| Food insecurity | 0.69 [0.55-0.88]* | 0.72 [0.55-0.93]* | 1.10 [0.99-1.22] | 1.04 [0.94-1.15] | 1.07 [0.96-1.19] | 1.01 [0.91-1.12] |
| Difficulty paying bills | 0.99 [0.75-1.29] | 0.86 [0.63-1.17] | 0.97 [0.85-1.10] | 1.00 [0.88-1.14] | 0.98 [0.88-1.10] | 0.99 [0.88-1.11] |
| Difficulty paying utilities | 0.96 [0.67-1.35] | 0.91 [0.61-1.35] | 0.94 [0.80-1.12] | 0.96 [0.82-1.15] | 1.02 [0.89-1.12] | 1.02 [0.89-1.17] |
| Transportation barriers | 0.49 [0.36-0.66]** | 0.44 [0.32-0.62]** | 1.22 [1.07-1.38]** | 1.21 [1.07-1.36]** | 1.05 [0.94-1.17] | 1.05 [0.94-1.16] |
| Frequent stress | 0.73 [0.58-0.93]* | 0.52 [0.40-0.68]** | 1.04 [0.93-1.17] | 1.12 [1.00-1.24]* | 1.53 [1.39-1.70]** | 1.54 [1.40-1.70]** |
| Age 35-54 | - | 0.47 [0.33-0.66]** | - | 1.19 [0.99-1.43] | - | 1.03 [0.89-1.19] |
| Age 55+ | - | 0.17 [0.12-0.24]** | - | 1.53 [1.26-1.85]** | - | 1.08 [0.92-1.27] |
| Female | - | 0.92 [0.74-1.16] | - | 0.93 [0.85-1.03] | - | 0.96 [0.88-1.06] |
| Income ≥ $25k | - | 1.37 [1.07-1.75]* | - | 0.78 [0.70-0.88]** | - | 0.89 [0.80-0.99]* |
| High school | - | 1.21 [0.89-1.64] | - | 0.86 [0.76-0.98]* | - | 0.81 [0.71-0.92]** |
| Some college/tech | - | 1.66 [1.18-2.35]* | - | 0.90 [0.79-1.02] | - | 0.89 [0.78-1.01] |
| College/tech | - | 2.22 [1.59-3.09]** | - | 0.91 [0.80-1.04] | - | 0.89 [0.78-1.02] |
| Divorced/widowed/ separated | - | 1.01 [0.79-1.28] | - | 0.99 [0.90-1.09] | - | 1.15 [1.03-1.29]* |
| Never married | - | 1.18 [0.85-1.63] | - | 0.85 [0.73-1.00] | - | 0.93 [0.80-1.08] |
| Unmarried couple | - | 0.94 [0.65-1.37] | - | 0.92 [0.77-1.10] | - | 0.98 [0.81-1.18] |

**Note.** OR = odds ratio; Exp(β) = exponentiated coefficient from quasi-Poisson regression; CI = confidence interval. Model I = unadjusted regression; Model II = adjusted for age, sex, income, education, and marital status. For logistic regression, ORs reflect the odds of reporting good/very good/excellent health (vs fair/poor). For count models, Exp(β) reflects the relative change in the number of poor physical or mental health days. All SDOH variables were coded such that 1 indicates the presence of the adverse condition. Reference categories are as follows: satisfied/very satisfied for life satisfaction; always/usually for emotional support; rarely/never for loneliness; no for employment loss, food assistance, and material hardship variables; male for sex; age 18–34 for age; < $25,000 for income; less than high school for education; and married for marital status. *p < .05, ***p < .001.*

## Supplemental

## Tables

**Supplemental Table 1.1** Unimputed Demographic and SDOH Characteristics of the Sample (n = 4,594)

| Variable | Category | n (%) / Mean (SD) |
|---|---|---|
| Age (years) | 18-34 | 918 (20.0) |
| | 35-54 | 1520 (33.1) |
| | 55+ | 2156 (46.9) |
| | Missing | - |
| Income | < $25,000 | 2447 (53.3%) |
| | ≥ $25,000 | 2147 (46.75%) |
| | Missing | 909 (19.7%) |
| Sex | Male | 1722 (37.5%) |
| | Female | 2872 (62.5%) |
| | Missing | - |
| Education | < High school | 513 (11.2) |
| | High school | 1135 (24.7%) |
| | Some college/Technical school | 1231 (26.8%) |
| | College/Technical school | 1715 (37.3%) |
| | Missing | 12 (0.3%) |
| Marital Status | Married | 1723 (37.5%) |
| | Divorced/Widowed/Separated | 1196 (26.0%) |
| | Never married | 1167 (25.4%) |
| | Unmarried couple | 508 (11.1%) |
| | Missing | 23 (0.5%) |
| Life Satisfaction | Satisfied/Very satisfied | 4389 (95.5%) |
| | Dissatisfied/Very dissatisfied | 205 (4.5%) |
| | Missing | 130 (2.8%) |
| Emotional Support | Always/Usually | 3809 (82.9%) |
| | Sometimes/Rarely/Never | 785 (17.1%) |
| | Missing | 119 (2.6%) |
| Loneliness | Rarely/Never | 2970 (64.6%) |
| | Always/Usually/Sometimes | 1624 (35.4%) |
| | Missing | 112 (2.4%) |
| Reduced Employment (Hours) | No | 4118 (89.6%) |
| | Yes | 476 (10.4%) |
| | Missing | 408 (8.9%) |

**Supplemental Table 1.1** Unimputed Demographic and SDOH Characteristics of the Sample (n = 4,594) (Continued)

| | | |
|---|---|---|
| Food Stamp Usage | No | 2555 (55.6%) |
| | Yes | 2039 (44.4%) |
| | Missing | 113 (2.5%) |
| Food Insecurity | Rarely/Never | 3581 (77.9%) |
| | Always/Usually/Sometimes | 1013 (22.1%) |
| | Missing | 112 (2.4%) |
| Difficulty Paying Bills | No | 3908 (85.1%) |
| | Yes | 686 (14.9%) |
| | Missing | 131 (2.9%) |
| Difficulty Paying Utilities | No | 4229 (92.1%) |
| | Yes | 365 (7.9%) |
| | Missing | 122 (2.7%) |
| Transportation Barriers | No | 4105 (89.4%) |
| | Yes | 489 (10.6%) |
| | Missing | 117 (2.5%) |
| Stress (in past 30 days) | Sometimes/Rarely/Never | 3646 (79.4%) |
| | Always/Usually | 948 (20.6%) |
| | Missing | 124 (2.7%) |
| Self-Rated General Health | Fair/Poor | 1513 (32.9%) |
| | Good/Very Good/Excellent | 3081 (67.1%) |
| | Missing | 1 (0.0%) |
| Self-Rated Physical Health (in past 30 days) | - | 14.5(11.1) |
| | Missing | 20 (0.00%) |
| Self-Rated Mental Health (in past 30 days) | - | 15.7(11.0) |
| | Missing | 34 (0.01%) |

# Chapter III

## ¿Detrás del síntoma, el sistema? Relative Importance of Social Determinants of Health in Classifying Health and Behavioral Outcomes Among Puerto Rican Adults

## Abstract

**Background.** Social determinants of health (SDOH) are well-established correlates of health disparities; however, most studies examine these factors in isolation and/or rely on analytic approaches that inadequately account for their relative importance in accounting for health outcomes. Further, limited research has evaluated the relative importance of SDOHs on diverse health outcomes among adults in Puerto Rico, a population experiencing persistent structural disadvantage and substantial health inequities resulting from colonialist policies.

**Methods.** This study examined the relative importance and classification accuracy of SDOH in accounting for chronic physical, mental, and behavioral health outcomes using a machine learning approach. Data were drawn from the 2023 Behavioral Risk Factor Surveillance System (BRFSS), including a representative sample of Puerto Rican adults aged 18 years and older ($n$ = 4,594).

**Results.** Bivariate analyses revealed that financial hardship and psychosocial stressors were associated with a broad range of chronic physical and mental health outcomes, with loneliness and perceived stress most strongly linked to depression. Elastic net models achieved the highest classification accuracy for depression, while classifying performance for most chronic physical conditions and substance use outcomes was modest. Key classifiers across outcomes included food insecurity, employment instability, stress, loneliness, and transportation barriers.

**Conclusion.** Findings highlight the complex and multidimensional nature of social vulnerability and emphasize limitations of cross-sectional, dichotomous SDOH measurement for classifying health outcomes. These insights highlight the need for longitudinal, multidimensional approaches to advance our understanding of health disparities and inform public health strategies aimed at promoting health equity in Puerto Rico.

## Introduction

The social determinants of health (SDOH) are non-medical conditions that shape individual and population health, including the circumstances in which people are born, grow, live, work, and age, as well as the broader social, economic, and political systems that influence these conditions (World Health Organization, n.d.). Core SDOH domains include economic stability, education, healthcare access and quality, neighborhood and built environment, and social and community context (Healthy People 2030, n.d.). SDOH affects health through interrelated material, psychosocial, and behavioral pathways. Extensive evidence demonstrates that SDOH are strong correlates of health outcomes, often exceeding medical care or genetic predisposition (Braveman & Gottlieb, 2014; Chelak & Chakole, 2023). Socioeconomic status consistently drives health disparities, with lower-income or less-educated individuals experiencing higher rates of disability, functional impairment, and premature mortality (Braveman et al., 2010). Material deprivation limits access to nutritious food, stable housing, transportation, and healthcare, increasing vulnerability to chronic illness, delayed diagnosis, and inadequate disease management (Braveman & Gottlieb, 2014; Enard et al., 2023). In Puerto Rico, however, longstanding historical, economic, and structural inequities—including colonial legacies, persistent poverty, political marginalization, and recurring natural disasters—have produced patterns of widespread social disadvantage that may differ from those of the United States (U.S.) mainland (Martin & Pace, 2025; McSorley et al., 2024). Despite these challenges, little is known about how multiple, intersecting social determinants collectively shape associated with patterns of health and disease within this population, emphasizing the need for a more comprehensive understanding of social risk. In response to this knowledge gap, the present study

used a machine learning approach to determine the relative importance and classification accuracy of SDOH in explaining health and behavioral outcomes among Puerto Rican adults.

**Conceptual Framework: Multidimensional and Interdependent SDOH**

The present study was guided by the SDOH framework and the National Institute on Minority Health and Health Disparities (NIMHD) Research Framework, which conceptualize health as the product of interactions among social, economic, environmental, behavioral, and biological factors at multiple levels (individual, interpersonal, community, structural; Lafarga Previdi and Vélez Vega, 2020). Health disparities emerge from the individual and cumulative risk exposures embedded in social systems rather than resulting solely from individual behaviors (National Institute on Minority Health and Health Disparities, 2025).

SDOH are multidimensional and frequently co-occur. Although dichotomous measurement of SDOH is common in large-scale surveillance data, these approaches may obscure meaningful gradients of risk and resilience across populations. Binary indicators can cover substantial heterogeneity in exposure intensity, chronicity, and vulnerability, which can underestimate the complexity of social adversity and limit the detection of nuanced associations between social conditions and health outcomes (Herrin et al., 2023). Economic instability, food insecurity, housing barriers, emotional distress, and social disconnection often cluster, producing compounded vulnerability (Lafarga Previdi & Vélez Vega, 2020). These intersecting risks simultaneously constrain material resources, heighten psychosocial stress, and limit healthcare access, amplifying disease risk and impeding management (Lafarga Previdi & Vélez Vega, 2020). Physical health outcomes are affected via delayed diagnosis, inadequate treatment, and stress-related biological pathways (National Institute on Minority Health and Health Disparities, 2025). Mental health outcomes are shaped by prolonged exposure to adversity, social isolation,

and discrimination, increasing vulnerability to mood and anxiety disorders (National Institute on Minority Health and Health Disparities, 2025). Behavioral outcomes, including substance use, often serve as coping responses to sustained stress, reinforcing cycles of disadvantage (National Institute on Minority Health and Health Disparities, 2025).

**SDOH in the Puerto Rican Context**

Puerto Rico represents a unique context in which SDOH are deeply shaped by historical, structural, and colonial processes. As a U.S. unincorporated territory, the island has experienced political disenfranchisement, constrained economic development, and structural dependency, producing persistent socioeconomic vulnerability and pronounced health inequities (Braveman & Gottlieb, 2014). Limited political autonomy restricts access to federal resources and social protections, exacerbating poverty, unemployment, and underinvestment in healthcare and social services (Santos-Burgoa et al., 2018). Chronic fiscal instability, population outmigration, and deterioration of public institutions further intensify material hardship and barriers to healthcare (Enard et al., 2023).

Natural disasters, including Hurricanes Irma and María (2017), further heightened these vulnerabilities by devastating infrastructure, disrupting essential services, and compounding preexisting inequalities (Santos-Burgoa et al., 2018; Kishore et al., 2018). Recovery was prolonged, disproportionately affecting older adults, individuals with disabilities, low-income households, and rural communities, thereby amplifying psychosocial stress and health risks.

Puerto Rico also faces a high burden of chronic disease and mental health conditions, including diabetes, cardiovascular disease, depression, and anxiety (Enard et al., 2023). SDOH rarely occur in isolation; overlapping forms of material hardship, social disadvantage, and environmental vulnerability increase cumulative health risk and widen disparities. Migration and

population displacement weaken traditional social support systems, increasing social isolation among older adults, and intensifying mental health vulnerability (Yelton et al., 2022). This convergence of social risks underscores the need for analytic approaches capable of accounting for interrelationships between SDOH domains to identify specific high value classifiers of health and behavioral outcomes within this population.

**SDOH and Machine Learning: Elastic Net Regression**

The interconnected nature of SDOH challenges traditional statistical methods, as high correlations among classifiers (multicollinearity) inflate standard errors, reduce statistical power, and obscure individual effects (Zou & Hastie, 2005; Vatcheva et al., 2016). Much of the existing literature examines SDOH by assessing individual associations between single determinants—such as income, education, or access to care—and health outcomes (Braveman et al., 2011; Kawachi et al., 1999). While these approaches have generated important evidence regarding social gradients in health, studies often rely on individual risk factors or composite indices, which may mask heterogeneity and the cumulative effects of co-occurring social risks (LaNoue et al., 2020). Machine learning approaches, such as elastic net regression, address these challenges by simultaneously modeling correlated classifiers and performing variable selection. Elastic net combines Least Absolute Shrinkage and Selection Operator (LASSO) and ridge regression, retaining groups of correlated variables while stabilizing coefficient estimates, improving interpretability and classifying accuracy (Tay et al., 2023). This approach is particularly suitable for SDOH research, where social risks co-occur and exert joint influences on health outcomes (Lin et al., 2024; Na et al., 2025).

Prior studies have applied machine learning methods to SDOH primarily to improve risk prediction and identify high-need populations, while emphasizing classification accuracy.

Research by Li and colleagues (2011) contrasted various machine learning algorithms utilizing SDOH of health as classifiers of heart failure and resulting length of stay in a hospital to determine their value in improving model bias against underserved populations. Algorithm performance was poor, across algorithms, but the inclusion of SDOH indicators contributed to classification decisions that were less biased. Segar and colleagues (2022) utilized a machine learning approach to examine to what extent SDOH of health classified patient in-hospital mortality among heart disease patients. Their findings suggest that SDOH indicators provide good to excellent classification of in-hospital mortality. Stabellini and colleagues (2023) also utilized a machine learning approach using SDOH of health as classifiers of cardiac outcomes among patients with breast cancer and found that these stressors contributed to excellent classification accuracy. Although these studies showed the utility of machine learning algorithms in classifying health outcomes associated with SDOH, they frequently had inconsistent classification accuracy, did not examine the relative importance of specific social risk factors and lacked an examination of a broader array of health outcomes (Li et al., 2022; Segar et al., 2022; Stabellini et al., 2023)

**The Present Study**

In Puerto Rico, historical, political, economic, and environmental factors produce high clustering of social risks and persistent health inequities. Yet few studies have applied methods capable of modeling high-dimensional, correlated exposures to various health outcomes. Despite evidence linking SDOH to health, gaps remain in understanding the relative importance of these risk factors and extent to which they classify health outcomes among Puerto Rican adults. This study uses the elastic net algorithm to examine the joint contributions of multiple SDOH domains to a broad array of health and behavioral outcomes among Puerto Rican adults. The

aims of the study were to a) characterize SDOH and health/behavioral outcome univariate associations and directionality, b) determine to what extent SDOH accurately classify health/behavioral outcomes, and c) identify specific high value classifiers across outcomes. It is hypothesized that material hardship (e.g., food insecurity, housing instability, financial strain) and psychosocial stressors (e.g., social isolation and unemployment) will emerge as the strongest classifiers, as extensive research demonstrates that economic deprivation and social stress are among the most powerful social determinants of health and are consistently associated with poorer self-rated health and other adverse health outcomes (Braveman et al., 2010; Braveman et al., 2011; Braveman & Gottlieb, 2014; Enard et al., 202). Findings from this research may clarify the complex pathways linking social disadvantage to specific health and behavioral outcomes, which can guide targeted public health interventions and policies to reduce disparities and promote the wellbeing of Puerto Ricans.

## Methods

### Data Source

Data for the present study were obtained from the 2023 Behavioral Risk Factor Surveillance System (BRFSS), an annual, cross-sectional health survey administered by the Centers for Disease Control and Prevention (CDC, 2024). The BRFSS collects population-based information on health-related behaviors, chronic conditions, and access to preventive services among adults aged 18 years and older across the United States and U.S. territories. The analytic sample was restricted to respondents who participated in the 2023 BRFSS and reported residing in Puerto Rico ($n$ = 4,594). Data were collected between July and December 2023 using a standardized questionnaire administered through computer-assisted telephone interviewing (CATI). Participants were selected via random-digit dialing of both landline and cellular telephone

numbers to ensure broad population coverage. Prior to participation, respondents provided verbal informed consent and were informed that participation was voluntary, that they could decline to answer any question, and that they could discontinue the interview at any time. The CATI system supported standardized question delivery and real-time data capture, contributing to data quality and consistency. Participants provided verbal informed consent prior to completing the survey, were told that identifying information would be kept confidential, and were informed that completing the survey was voluntary and that they could discontinue at any time. The University of Tennessee, Knoxville Institutional Review Board approved secondary analyses of the 2023 BRFSS data as being non-human subjects research. Unimputed values of participants' demographic characteristics are described in Supplemental Table 2.1.

## Measures

### *Demographics*

Participants provided information on age, sex, race/ethnicity, household income, and educational attainment. Age was grouped into six categories: 18–24, 25–34, 35–44, 45–54, 55–64, and 65 years or older. Sex was coded as male or female. Race and ethnicity were self-identified and categorized as White, Black or African American, Hispanic or Latino, Asian, Native Hawaiian or Other Pacific Islander, American Indian or Alaska Native, mixed race, or other. Annual household income was reported in seven brackets: less than $15,000; $15,000 to less than $25,000; $25,000 to less than $35,000; $35,000 to less than $50,000; $50,000 to less than $100,000; $100,000 to less than $200,000; and $200,000 or more. Educational attainment was assessed as less than a high school diploma, high school graduate or equivalent, some college or technical education, and completion of a college or technical degree. Race and

ethnicity were not included in this analysis, as over 99% of the survey respondents residing in Puerto Rico were Hispanic.

### *SDOH*

SDOH were assessed using ten indicators capturing exposure to social stressors and structural vulnerabilities. These indicators included low life satisfaction, limited emotional support, social isolation, unemployment or job loss, food insecurity, receiving food assistance, difficulty paying monthly bills, loss of or threatened loss of utility services due to nonpayment, transportation barriers, and elevated perceived stress. All SDOH indicators were coded dichotomously (0 = *No*, 1 = *Yes*). Collectively, these measures represent multiple dimensions of social vulnerability, including economic instability, social disconnection, and unmet material and access-related needs.

### *Chronic Health Conditions*

Participants reported whether a healthcare professional had ever told them that they had been diagnosed with specific chronic health conditions. Cardiovascular conditions included heart attack, angina or coronary heart disease, and stroke. Respiratory conditions included asthma and chronic obstructive pulmonary disease (COPD), emphysema, or chronic bronchitis. Additional conditions assessed were diabetes, kidney disease, arthritis-related conditions (including arthritis, rheumatoid arthritis, gout, lupus, or fibromyalgia), and cancer diagnoses, including skin cancer and melanoma. Depression was included as an indicator of mental health. The presence of a chronic condition was coded dichotomously (0 = *No*, 1 = *Yes*).

### Behavioral Health

Behavioral health outcomes included recent alcohol use, cigarette smoking, and electronic cigarette use. Past-month alcohol consumption was defined as having consumed at least one

alcoholic beverage in the past 30 days. Current cigarette smoking was defined as smoking cigarettes every day or some days at the time of the survey. Electronic cigarette use was defined as current use of e-cigarettes or other vaping products. Each behavioral health variable was coded dichotomously (0 = *no*, 1 = *yes*).

**Analytic Plan**

All analyses were conducted in R (version 4.5.0; R Core Team, 2025) and R Studio (version 2024.12.1+563; R Studio Team, 2024) using the caret (Kuhn, 2008), mice (van Buuren & Groothuis-Oudshoorn, 2011), psych (Revelle, 2024), furniture (Barrett, 2023), tidyverse (Wickham et al., 2019), and corrplot (Wei & Simko, 2023) packages. Within the present sample, 1.8% of all possible responses on study variables of interest were missing. The most common pattern was 23.6% of participants missing responses on one variable (predominantly on the income variable). The pattern of missingness was significantly related to variables of interest, with respondents reporting higher risk categories for SDOH and outcome variables being largely more likely to have missing data. Thus, data were treated as being Missing Not at Random (MNAR). Descriptive statistics were computed using tests appropriate to variable type (Kruskal-Wallis for continuous, chi-square for categorical variables) (Chicco et al., 2025). Tetrachoric correlations were calculated to examine the relationships among dichotomous SDOH indicators, and study outcomes, as this is a recommended method for estimating associations between binary variables (Drasgow & Muthén, 1982).

Elastic Net regression was used as the primary analytic method to evaluate the classification accuracy and relative importance of SDOH for study outcomes. A separate Elastic Net model was fit for each outcome variable to determine to what extent multiple SDOH collectively explained differences in health risks. To address class imbalance that can affect

model sensitivity and specificity, a down-sampling procedure was applied, which reduces the sample size of the majority class (i.e., does not have disorder/behavior) to match the minority category (i.e., has the disorder/behavior). This procedure helps produce accuracy metrics that represent a balance between sensitivity and specificity (Chawla et al., 2002; Kuhn, 2008).

Model performance was evaluated using the Area Under the Receiver Operating Characteristic Curve (AUC), which measures the model's ability to correctly distinguish between outcome categories. AUC values ≥ 0.70 were considered indicative of acceptable classification performance (AUC < 70 = poor, 70-80 = acceptable, 80-90 = excellent, > 90 = outstanding discrimination) (Fawcett, 2006; Hosmer, & Lemeshow, 2000). Relative importance of classifiers was calculated to determine which SDOH variables contributed most to model classification performance. A variable is considered of high importance if including it in the model substantially improves the classification accuracy of the algorithm. High value classifiers were identified using the elbow method, visually inspecting ranked importance plots to detect meaningful separation between high and low information variables (Tay et al., 2023). To reduce overfitting and improve generalizability, both AUC and relative importance metrics were estimated using bootstrapped cross-validation with 1,000 iterations (Efron & Tibshirani, 1994). This procedure provides robust estimates of model performance and ensures that identified SDOH reliably classify health outcomes in the sample.

## Results

### Descriptives

Table 2.1 presents descriptive statistics for SDOH, chronic health conditions, and substance use outcomes based on the imputed sample. The most frequently endorsed SDOH indicators were receiving food assistance (44.3%), social isolation (35.4%), and food insecurity

(22.2%). In contrast, the least commonly reported indicators included low life satisfaction (4.4%), threatened loss of utility services (7.9%), and transportation barriers (10.6%). The most prevalent chronic conditions were arthritis-related conditions (28.2%), current asthma (61.8%), and diabetes (18.8%). Less commonly reported conditions included kidney disease (4.4%), stroke (2.6%), and skin cancer (1.1%). Regarding mental and behavioral health outcomes, 17.3% of participants reported a prior diagnosis of depression. In terms of substance use, 32.5% reported alcohol consumption in the past 30 days, 7.4% were current cigarette smokers, and 1.7% reported current use of electronic cigarettes. Unimputed frequencies and distributions are presented in Supplemental Table 2.2.

**Correlations Among SDOH Indicators**

Tetrachoric correlations among SDOH and health outcomes are presented in Figure 2.1. Moderate positive correlations were observed among measures of SDOH. Financial hardship indicators such as ability to pay monthly bills were strongly correlated with threatened loss of utility services ($r = 0.72$) and moderately correlated with food insecurity ($r = 0.59$). Transportation barriers were positively correlated with both food insecurity ($r = 0.44$) and threatened loss of utility services ($r = 0.44$). Life satisfaction was positively correlated with emotional support ($r = 0.52$) and loneliness ($r = 0.52$); while emotional support was positively correlated with loneliness ($r = 0.54$). Perceived stress was positively correlated with both life satisfaction ($r = 0.53$) and loneliness ($r = 0.50$).

Health indicators showed generally weaker correlations with social determinants, though some moderate associations were noted. For instance, cardiovascular conditions such as experiencing a heart attack and being diagnosed with angina or coronary heart disease had a positive correlation ($r = 0.68$). Experiencing a stroke was moderately correlated with

experiencing a heart attack ($r$ = 0.48) and being diagnosed with angina or coronary heart disease ($r$ = 0.37). Respiratory conditions such as C.O.P.D, emphysema, or chronic bronchitis and asthma were also positively correlated ($r$ = 0.51). Diabetes was negatively correlated with kidney disease ($r$ = -0.43), heart attacks ($r$ = -0.42), coronary heart disease ($r$ = -0.39), and arthritis kidney disease ($r$ = -0.35). Depression was positively correlated with life satisfaction ($r$ = 0.53) and social stressors, including loneliness ($r$ = 0.52) and stress ($r$ = 0.35). Substance use variables displayed mostly weak correlations with both health and social determinant variables, though vaping was moderately associated with some psychosocial stressors such as loneliness ($r$ = 0.31) in addition to smoking ($r$ = 0.43).

**Elastic Net Algorithm**

Elastic net logistic regression models were trained for each of the 14 health outcomes using 10 SDOH classifiers. Sample sizes ranged from 100 (skin cancer) to 2,982 (alcohol use). Across models, AUC values, sensitivities, and specificities varied by outcome (see Table 2.2 for full model performance metrics). The highest AUC was observed for depression (AUC = 0.77), and the lowest for melanoma (AUC = 0.52). Sensitivity and specificity also differed across models; for example, the stroke model had a sensitivity of 0.75 and a specificity of 0.44, while the depression model had a sensitivity of 0.75 and a specificity of 0.68. Figure 2 presents the relative importance of the ten SDOH indicators included in the elastic net logistic regression models across the fourteen health outcomes. Each panel represents an outcome, with sample size and AUC indicated. Across all models, variable importance values reflect each classifier's contribution in improving the algorithm's accuracy, with higher values indicating stronger classifying influence. Overall, employment status, food-related hardship, stress and transportation emerged as consistently high ranked classifiers across a wide range of outcomes.

However, the relative importance of specific SDOH varied by health condition, highlighting the uniqueness of social risk profiles across different disease domains.

For cardiovascular outcomes, the relative importance of SDOH classifiers varied by condition. Heart attacks were most strongly classified by employment loss, threatened utility loss, and food stamp usage, whereas coronary heart disease was primarily driven by food stamp usage and stress. In contrast, transportation barriers emerged as the most important classifier for stroke. Among respiratory conditions, including asthma and COPD (emphysema or chronic bronchitis), stress, food insecurity, and loneliness showed the greatest importance. Cancer-related outcomes, including skin cancer and melanoma or other cancers, were most strongly classified by employment loss, food insecurity, life dissatisfaction, and emotional support. Employment loss and food stamp usage consistently emerged as the two most important classifiers for kidney disease, arthritis (including rheumatoid arthritis, gout, lupus, and fibromyalgia) and diabetes. Depression was predominantly classified by stress and loneliness. For behavioral outcomes, the relative importance of SDOH classifiers varied across behaviors. Alcohol consumption was most strongly classified by food stamp usage, whereas smoking was primarily classified by food insecurity, employment loss, and stress. E-cigarette use showed a broader pattern, with employment loss, stress, food stamp usage, and life dissatisfaction contributing most substantially to classification performance.

## Discussion

This study examined the multidimensional contributions of SDOH to chronic health conditions and behavioral health outcomes among adults in Puerto Rico using the elastic net algorithm. By integrating population-level surveillance data with advanced analytic methods, this work expands existing literature by providing a multidimensional perspective on the relative

importance of social risks that may shape health and behavioral outcomes in a structurally vulnerable population. Our findings highlight the complexity of social vulnerabilities and highlight important methodological and conceptual considerations for advancing health disparities research in Puerto Rico and other similar settings.

Bivariate analyses revealed associations between individual SDOH indicators and health outcomes. Financial hardship indicators including food insecurity, food stamp use, and difficulty paying bills were moderately associated with chronic disease outcomes such as diabetes, arthritis, kidney disease, and cardiovascular conditions. These findings align with extensive literature linking material deprivation to cardiometabolic risk, impaired disease management, and delayed healthcare utilization (Enard et al., 2023; Braveman & Gottlieb, 2014). Psychosocial stressors, including loneliness, perceived stress, and limited emotional support, showed the strongest associations with depression, consistent with prior research documenting the central role of social connection and chronic stress in shaping mental health (Na et al., 2025; Lin et al., 2024). Associations between psychosocial stressors and respiratory conditions further support evidence that chronic stress may exacerbate inflammatory and respiratory processes through neuroendocrine and immune pathways. Behavioral outcomes demonstrated weaker and more inconsistent bivariate associations, suggesting that behavioral health risks may be shaped by more complex, context-dependent pathways. This aligns with prior findings that substance use behaviors may be influenced by broader environmental, cultural, and psychological factors beyond immediate material hardship (Galea & Vlahov, 2002; Lin et al., 2024).

Elastic net revealed that classification accuracy varied markedly across health outcomes. SDOH demonstrated the strongest classification performance for depression (AUC = 0.77), with stress and loneliness emerging as dominant classifiers. This finding reinforces existing

conceptualizations of depression as deeply embedded within psychosocial contexts and validates the relevance of SDOH-based screening strategies for mental health risk. In contrast, classification accuracy was modest to poor for most chronic physical conditions and behavioral outcomes. Employment loss, food-related hardship, stress, and transportation barriers consistently emerged as influential classifiers across models, yet their combined classifying capacity remained limited. This suggests that while these SDOH are relevant contributors, they alone may not sufficiently capture the complexity of disease etiology and behavioral risk. Additionally, these findings highlight the limitations of dichotomous SDOH measurement and conventional classifying frameworks. The modest classification performance suggests that current surveillance-based indicators may inadequately capture the severity, chronicity, and cumulative burden of social adversity. As a result, there is a need to rethink how SDOH are operationalized and measured in population health research.

One of the most notable and unexpected findings was the relatively poor classification accuracy across most health outcomes. Given the extensive literature documenting strong associations between SDOH and health, higher classifying performance was anticipated. Several explanations may account for this pattern. First, the cross-sectional nature of the data limits causal inference and obscures temporal ordering. SDOH may function not only as determinants but also as consequences of poor health. A recent nationally representative study found that food insecurity and chronic health conditions are strongly linked, and the authors explicitly note that there are likely bidirectional relationships between food insecurity and chronic conditions (Berrett-Abebe & Reed, 2024). This reciprocal dynamic complicates classifying modeling and challenges linear causal assumptions. Second, the dichotomous measurement of both SDOH and health outcomes likely reduces sensitivity to meaningful gradients in exposure and disease severity (McGuire et

al., 2024). Individuals classified as "exposed" may experience vastly different intensities, durations, and trajectories of hardship, which may differentially influence health outcomes. Similarly, disease severity, duration, and functional impairment are not captured by binary diagnostic indicators, limiting explanatory power (Altman & Royston, 2006). Third, the modest classification accuracy suggests that unmeasured factors—including environmental exposures, healthcare quality, neighborhood characteristics, cultural contexts, and cumulative life-course adversity—may play substantial roles in shaping health risk (Lafarga Previdi & Vélez Vega, 2020). These findings emphasize the need for more comprehensive, multidimensional measurement frameworks.

**Implications**

In the Puerto Rican context, these findings hold significant implications for addressing health disparities. Structural inequalities shaped by colonial governance, economic instability, population displacement, and repeated natural disasters have produced widespread material hardship and psychosocial stress (Braveman & Gottlieb, 2014). The observed clustering of food insecurity, employment loss, transportation barriers, and emotional distress reflects the lived realities of many Puerto Rican residents and emphasizes the systemic nature of social vulnerability on the island.

The strong classification of depression by stress and loneliness highlights the critical role of psychosocial pathways in shaping mental health, particularly within communities facing prolonged adversity. Disruptions to social networks due to migration, displacement, and natural disasters may intensify social isolation and emotional distress, contributing to elevated mental health burden (Yelton et al., 2022). These findings emphasize the importance of strengthening community-based social support systems and integrating mental health services into primary care

and public health programming. Furthermore, the consistent importance of food-related hardship and employment instability across multiple physical and behavioral health outcomes points to the central role of economic insecurity in contributing to health disparities. Interventions that address food access, income stability, and employment opportunities may provide broad population-level health benefits. Importantly, these findings suggest that addressing upstream social conditions may be more impactful than narrowly targeting individual health behaviors.

Collectively, these findings also challenge the dominant framing of SDOH solely as upstream determinants and instead support conceptual models that view social risk and health outcomes as dynamically intertwined. Health conditions may deepen social vulnerability, while social hardship may worsen disease progression, creating reinforcing cycles of disadvantage (Berkman & Kawachi, 2014). This study highlights the urgent need for longitudinal research designs capable of disentangling temporal ordering and reciprocal causality. Prospective cohort studies incorporating repeated assessments of social risk, disease severity, and functional status would provide critical insight into dynamic pathways linking SDOH and health.

Furthermore, future research should prioritize measurement strategies that capture the type, intensity, chronicity, and accumulation of social adversity. Continuous and multi-item indices, rather than low information dichotomous indicators, may substantially enhance classifying accuracy and conceptual clarity. Similarly, incorporating measures of neighborhood context, healthcare access, environmental exposures, and policy-level factors would provide a more holistic understanding of health vulnerability.

**Limitations**

Several limitations of this study warrant consideration. First, the cross-sectional design did not allow for causal inference and limited interpretations regarding the temporal order

between classifiers and outcomes. Second, reliance on self-reported data introduces potential recall bias and misclassification, particularly for chronic conditions and substance use behaviors. Third, the dichotomous measurement of SDOH and health outcomes likely weakened observed associations and reduced classification accuracy. Thus, research is needed to determine whether classification accuracy can be improved through the use of higher information measures of SDOHs. Fourth, machine learning models remain sensitive to their training data and may not fully generalize to other populations or contexts. Finally, the BRFSS lacks measures capturing severity, duration, and life-course exposure to both social risk and disease, limiting explanatory depth.

**Conclusions**

This study provides critical insight into complex relationships between SDOH and health outcomes among Puerto Ricans. By using a machine learning approach, our findings highlight both the centrality of social risk and the limitations of current measurement and analytic frameworks. The modest classification accuracy observed across most outcomes emphasizes the need to rethink how SDOH are conceptualized, measured, and modeled. Rather than functioning solely as upstream determinants, SDOH can also operate within dynamic, reciprocal systems that link social vulnerability and health across the life course. Understanding and addressing health disparities in Puerto Rico will require comprehensive, longitudinal, and multidimensional approaches that capture the depth, persistence, and structural roots of social adversity. Interventions targeting economic stability, food access, transportation, and social connection may be promising targets for reducing population-level disease burden and advancing health equity on the island.

## References


Adler, N. E., Cutler, D. M., Fielding, J. E., Galea, S., Glymour, M. M., Koh, H. K., & Satcher, D. (2016). Addressing social determinants of health and health disparities: A vital direction for health and health care. *National Academy of Medicine Perspectives*.

Altman, D. G., & Royston, P. (2006). The cost of dichotomising continuous variables. BMJ (Clinical research ed.), 332(7549), 1080. https://doi.org/10.1136/bmj.332.7549.1080

Barrett, T. (2023). furniture: Furniture for quantitative scientists. R package version 2.3.2. https://CRAN.R-project.org/package=furniture

Berkman, L. F., & Kawachi, I. (2014). Social epidemiology (2nd ed.). Oxford University Press.

Berrett-Abebe, J., & Reed, S. C. (2024). Exploring the Relationship between Food Insecurity, Chronic Health Conditions, and Serious Mental Illness in the United States: Implications for Social Work. Health & social work, 49(3), 147–156. https://doi.org/10.1093/hsw/hlae012

Braveman, P. A., Cubbin, C., Egerter, S., Williams, D. R., & Pamuk, E. (2010). Socioeconomic disparities in health in the United States: what the patterns tell us. American journal of public health, 100 Suppl 1(Suppl 1), S186–S196. https://doi.org/10.2105/AJPH.2009.166082

Braveman, P., Egerter, S., & Williams, D. R. (2011). The social determinants of health: coming of age. Annual review of public health, 32, 381–398. https://doi.org/10.1146/annurev-publhealth-031210-101218

Braveman, P., & Gottlieb, L. (2014). The social determinants of health: it's time to consider the causes of the causes. Public health reports (Washington, D.C. : 1974), 129 Suppl 2(Suppl 2), 19–31. https://doi.org/10.1177/00333549141291S206

Caron, P. (2025). poLCAExtra: New and Convenient Functions for the Package 'poLCA'. R package version 0.1. https://github.com/quantmeth/poLCAExtra

Chawla, N. V., Bowyer, K. W., Hall, L. O., & Kegelmeyer, W. P. (2002). SMOTE: Synthetic Minority Over-sampling Technique. The Journal of Artificial Intelligence Research, 16, 321–357. https://doi.org/10.1613/jair.953

Centers for Disease Control and Prevention. (2024, February 9). Behavioral Risk Factor Surveillance System (BRFSS). U.S. Department of Health and Human Services. https://www.cdc.gov/brfss/index.html

Chelak, K., & Chakole, S. (2023). The Role of Social Determinants of Health in Promoting Health Equality: A Narrative Review. Cureus, 15(1), e33425. https://doi.org/10.7759/cureus.33425

Chicco, D., Sichenze, A., & Jurman, G. (2025). A simple guide to the use of Student's t-test, Mann-Whitney U test, Chi-squared test, and Kruskal-Wallis test in biostatistics. BioData mining, 18(1), 56. https://doi.org/10.1186/s13040-025-00465-6

Drasgow, F., & Lissak, R. I. (1983). Modified parallel analysis: A procedure for examining the latent dimensionality of dichotomously scored item responses. Journal of Applied Psychology, 68(3), 363–373. https://doi.org/10.1037/0021-9010.68.3.363

Efron, B., & Tibshirani, R. (1994). An introduction to the bootstrap. Chapman & Hall. https://doi.org/10.1007/978-1-4899-4541-9

Enard, K. R., Coleman, A. M., Yakubu, R. A., Butcher, B. C., Tao, D., & Hauptman, P. J. (2023). Influence of Social Determinants of Health on Heart Failure Outcomes: A Systematic Review. Journal of the American Heart Association, 12(3), e026590. https://doi.org/10.1161/JAHA.122.026590

Fawcett, T. (2006). An introduction to ROC analysis. Pattern Recognition Letters, 27(8), 861–874. https://doi.org/10.1016/j.patrec.2005.10.010

Frontera-Escudero, I., Bartolomei, J. A., Rodríguez-Putnam, A., & Claudio, L. (2023). Sociodemographic and health risk factors associated with health-related quality of life among adults living in Puerto Rico in 2019: a cross-sectional study. BMC public health, 23(1), 2150. https://doi.org/10.1186/s12889-023-17115-3

Galea, S., & Vlahov, D. (2002). Social determinants and the health of drug users: socioeconomic status, homelessness, and incarceration. Public health reports (Washington, D.C. : 1974), 117 Suppl 1(Suppl 1), S135–S145.

Healthy People 2030, U.S. Department of Health and Human Services, Office of Disease Prevention and Health Promotion. Retrieved from https://health.gov/healthypeople/objectives-and-data/social-determinants-health

Herrin, J., Barthel, A., Goutos, D., Du, C., Zhou, S., Peltz, A., Poyer, J., Lin, Z., & Bernheim, S. (2023). Measuring health disparities using a continuous social risk factor. Health services research, 58(1), 30–39. https://doi.org/10.1111/1475-6773.14048

Hosmer, D.W., & Lemeshow, S. (2000). *Applied logistic regression*. New York: Wiley.

Kawachi, I., Kennedy, B. P., & Glass, R. (1999). Social capital and self-rated health: a contextual analysis. American journal of public health, 89(8), 1187–1193. https://doi.org/10.2105/ajph.89.8.1187

Kuhn, Max (2008). "Building Predictive Models in R Using the caret Package." Journal of Statistical Software, 28(5), 1–26. doi:10.18637/jss.v028.i05, https://www.jstatsoft.org/index.php/jss/article/view/v028i05.

Lafarga Previdi, I., & Vélez Vega, C. M. (2020). Health Disparities Research Framework

Adaptation to Reflect Puerto Rico's Socio-Cultural Context. International journal of environmental research and public health, 17(22), 8544. https://doi.org/10.3390/ijerph17228544

LaNoue, M. D., George, B. J., Helitzer, D. L., & Keith, S. W. (2020). Contrasting cumulative risk and multiple individual risk models of the relationship between Adverse Childhood Experiences (ACEs) and adult health outcomes. BMC medical research methodology, 20(1), 239. https://doi.org/10.1186/s12874-020-01120-w

Larmarange J (2025). ggstats: Extension to 'ggplot2' for Plotting Stats. R package version 0.12.0, https://larmarange.github.io/ggstats/

Li, Y., Wang, H., & Luo, Y. (2022). Improving Fairness in the Prediction of Heart Failure Length of Stay and Mortality by Integrating Social Determinants of Health. Circulation. Heart failure, 15(11), e009473. https://doi.org/10.1161/CIRCHEARTFAILURE.122.009473

Lin, C., Cousins, S. J., Zhu, Y., Clingan, S. E., Mooney, L. J., Kan, E., Wu, F., & Hser, Y. I. (2024). A scoping review of social determinants of health's impact on substance use disorders over the life course. Journal of substance use and addiction treatment, 166, 209484. https://doi.org/10.1016/j.josat.2024.209484

Martin, J. N., & Pace, T. W. W. (2025). Colonialism as a Social Determinant of Health in Puerto Rico: Using the Socioecological Model to Examine How the Jones Act Impacted Health After Hurricane María. Journal of transcultural nursing: official journal of the Transcultural Nursing Society, 36(1), 8–15. https://doi.org/10.1177/10436596241274123

McGuire, A., Singh, A., & Jackson, Y. (2024). Let it go, let it go: Stop measuring child

maltreatment as a binary yes/no. Child abuse & neglect, 155, 106994. https://doi.org/10.1016/j.chiabu.2024.106994

McSorley, A. M., Rivera-González, A. C., Mercado, D. L., Pagán, J. A., Purtle, J., & Ortega, A. N. (2024). United States Federal Policies Contributing to Health and Health Care Inequities in Puerto Rico. American journal of public health, 114(S6), S478–S484. https://doi.org/10.2105/AJPH.2024.307585

Muthén, B. (1978). Contributions to Factor Analysis of Dichotomous Variables. Psychometrika, 43(4), 551–560. doi:10.1007/BF02293813

Na, P. J., Shin, J., Kwak, H. R., Lee, J., Jester, D. J., Bandara, P., Kim, J. Y., Moutier, C. Y., Pietrzak, R. H., Oquendo, M. A., & Jeste, D. V. (2025). Social Determinants of Health and Suicide-Related Outcomes: A Review of Meta-Analyses. JAMA psychiatry, 82(4), 337–346. https://doi.org/10.1001/jamapsychiatry.2024.4241

National Institute on Minority Health and Health Disparities (2025). NIMHD Research Framework. Retrieved from https://nimhd.nih.gov/researchFramework

Patil, I. (2021). Visualizations with statistical details: The 'ggstatsplot' approach. Journal of Open Source Software, 6(61), 3167. https://doi.org/10.21105/joss.03167

Revelle, W. (2024). psych: Procedures for personality and psychological research (Version 2.4.1). Northwestern University. https://CRAN.R-project.org/package=psych

Segar, M. W., Hall, J. L., Jhund, P. S., Powell-Wiley, T. M., Morris, A. A., Kao, D., Fonarow, G. C., Hernandez, R., Ibrahim, N. E., Rutan, C., Navar, A. M., Stevens, L. M., & Pandey, A. (2022). Machine Learning-Based Models Incorporating Social Determinants of Health vs Traditional Models for Predicting In-Hospital Mortality in Patients With Heart Failure. JAMA cardiology, 7(8), 844–854.

https://doi.org/10.1001/jamacardio.2022.1900

Stabellini, N., Cullen, J., Moore, J. X., Dent, S., Sutton, A. L., Shanahan, J., Montero, A. J., & Guha, A. (2023). Social Determinants of Health Data Improve the Prediction of Cardiac Outcomes in Females with Breast Cancer. Cancers, 15(18), 4630. https://doi.org/10.3390/cancers15184630

Tay, J. K., Narasimhan, B., & Hastie, T. (2023). Elastic Net Regularization Paths for All Generalized Linear Models. Journal of statistical software, 106, 1. https://doi.org/10.18637/jss.v106.i01

Trujillo, M. A., Perrin, P. B., Sutter, M., Tabaac, A., & Benotsch, E. G. (2017). The buffering role of social support on the associations among discrimination, mental health, and suicidality in a transgender sample. *The International Journal of Transgenderism*, *18*(1), 39–52. https://doi.org/10.1080/15532739.2016.1247405

van Buuren, S., & Groothuis-Oudshoorn, K. (2011). mice: Multivariate imputation by chained equations in R. Journal of Statistical Software, 45(3), 1–67. https://doi.org/10.18637/jss.v045.i03

Vatcheva, K. P., Lee, M., McCormick, J. B., & Rahbar, M. H. (2016). Multicollinearity in Regression Analyses Conducted in Epidemiologic Studies. Epidemiology (Sunnyvale, Calif.), 6(2), 227. https://doi.org/10.4172/2161-1165.1000227

Vu, M., Li, J., Haardörfer, R. et al. Mental health and substance use among women and men at the intersections of identities and experiences of discrimination: insights from the intersectionality framework. BMC Public Health 19, 108 (2019). https://doi.org/10.1186/s12889-019-6430-0

Wei T, Simko V (2024). R package 'corrplot': Visualization of a Correlation Matrix. (Version

0.95), https://github.com/taiyun/corrplot

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., ... & Yutani, H. (2019). Welcome to the tidyverse. Journal of Open Source Software, 4(43), 1686. https://doi.org/10.21105/joss.01686

World Health Organization. (n.d.). Social determinants of health. https://www.who.int/health-topics/social-determinants-of-health

Yelton, B., Friedman, D. B., Noblet, S., Lohman, M. C., Arent, M. A., Macauda, M. M., Sakhuja, M., & Leith, K. H. (2022). Social Determinants of Health and Depression among African American Adults: A Scoping Review of Current Research. International journal of environmental research and public health, 19(3), 1498. https://doi.org/10.3390/ijerph19031498

Yoo, W., Mayberry, R., Bae, S., Singh, K., Peter He, Q., & Lillard, J. W., Jr (2014). A Study of Effects of MultiCollinearity in the Multivariable Analysis. International journal of applied science and technology, 4(5), 9–19.

Zou, H., & Hastie, T. (2005). Regularization and variable selection via the elastic net. Journal of the Royal Statistical Society. Series B, Statistical Methodology, 67(2), 301–320. https://doi.org/10.1111/j.1467-9868.2005.00503.x

## Appendix

## Tables and Figures

**Table 2.1** Imputed SDOH, Chronic Disorders, and Indicators of Wellbeing and Behavioral Health

| Variables | Mean/Count (SD/%) ($n$ = 4594) |
|---|---|
| **Age** | |
| 18-24 | 280 (6.1%) |
| 25-34 | 638 (13.9%) |
| 35-44 | 676 (14.7%) |
| 45-54 | 844 (18.4%) |
| 55-64 | 919 (20%) |
| 65+ | 1237 (26.9%) |
| **Sex** | |
| Male | 1722 (37.5% |
| Female | 2872 (62.5%) |
| **Race/ethnicity** | |
| Hispanic | 4553 (99.1%) |
| White | 28 (0.6%) |
| Black | 10 (0.2%) |
| Multiple | 2 (0%) |
| Other | 1 (0%) |
| **Education** | |
| Less than high school | 516 (11.2%) |
| High school | 1135 (24.7% |
| Some college/tech | 1231 (26.8%) |
| College/tech | 1712 (37.3%) |
| **Income** | |
| < 15,000 | 1321 (28.8%) |
| 15,000-<25,000 | 1118 (24.3%) |
| 25,000-<35,000 | 747 (16.3%) |
| 35,000-<50,000 | 672 (14.6%) |
| 50,000-<100,000 | 541 (11.8%) |
| 100,000-<200,000 | 147 (3.2%) |
| **SDOH** | |
| Life dissatisfaction | 203 (4.4%) |
| Emotional support | 779 (17%) |
| Loneliness | 1625 (35.4%) |

**Table 2.1** Imputed SDOH, Chronic Disorders, and Indicators of Wellbeing and Behavioral Health

(Continued)

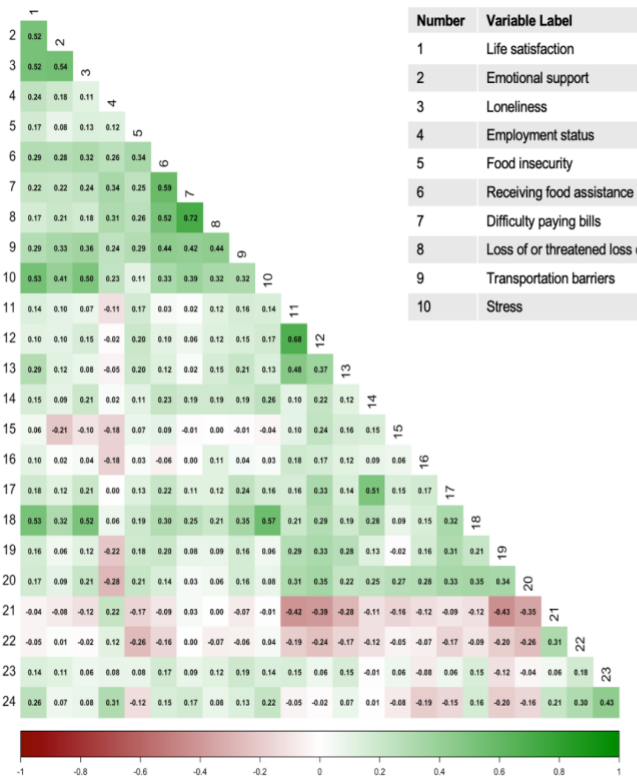
| | |
|---|---|
| Employment loses | 479 (10.4%) |
| Food stamps | 2040 (44.4%) |
| Food insecurity | 1021 (22.2%) |
| Paying bills | 684 (14.9%) |
| Threatened loss of utilities | 365 (7.9%) |
| Transportation | 485 (10.6%) |
| Stress | 954 (20.8%) |
| Cumulative SDOH | 1.9 (1.8) |
| **Chronic disorders** | |
| Heart attack | 223 (4.9%) |
| Angina or coronary heart disease | 257 (5.6%) |
| Stroke | 118 (2.6%) |
| Asthma | 969 (21.1%) |
| Skin cancer | 50 (1.1%) |
| Melanoma | 342 (7.4%) |
| COPD, emphysema, or chronic bronchitis | 278 (6.1%) |
| Depression | 797 (17.3%) |
| Kidney disease | 202 (4.4%) |
| Arthritis, rheumatoid arthritis, gout, lupus, or fibromyalgia | 1296 (28.2%) |
| Diabetes | 865 (18.8%) |
| **Wellbeing and behavioral health** | |
| Alcohol use | 1491 (32.5%) |
| Tobacco use | 342 (7.4%) |
| Electronic cigarette use | 79 (1.7%) |

*Notes:* SDOH = Social determinants of health.

**Table 2.1** Classification Performance of Final LASSO Logistic Regression Models Across Health Outcomes

| Outcome | Sample Size | α (Alpha) | λ (Lambda) | AUC | Sensitivity | Specificity |
|---|---|---|---|---|---|---|
| Heart attack | 446 | 1.00 | 0.0148 | 0.600 | 0.607 | 0.561 |
| Coronary Heart Disease | 514 | 1.00 | 0.0160 | 0.579 | 0.568 | 0.541 |
| Stroke | 236 | 0.55 | 0.0280 | 0.633 | 0.734 | 0.455 |
| Asthma | 1,938 | 0.55 | 0.0163 | 0.615 | 0.648 | 0.515 |
| Skin Cancer | 100 | 1.00 | 0.0200 | 0.531 | 0.480 | 0.545 |
| Melanoma / Other Cancer | 684 | 1.00 | 0.0124 | 0.518 | 0.455 | 0.561 |
| COPD / Emphysema / Chronic Bronchitis | 556 | 1.00 | 0.0171 | 0.594 | 0.653 | 0.488 |
| Depression | 1,594 | 0.10 | 0.0400 | 0.768 | 0.698 | 0.720 |
| Kidney disease | 404 | 1.00 | 0.0193 | 0.629 | 0.602 | 0.583 |
| Arthritis / RA / Gout / Lupus / Fibromyalgia | 2,592 | 1.00 | 0.0148 | 0.636 | 0.548 | 0.650 |
| Diabetes | 1,730 | 0.55 | 0.0115 | 0.589 | 0.566 | 0.570 |
| Any Alcohol Past 30 Days | 2,982 | 0.55 | 0.0165 | 0.598 | 0.512 | 0.652 |
| Current Smokers | 684 | 1.00 | 0.0150 | 0.565 | 0.686 | 0.425 |
| Current E-cigarette Users | 158 | 1.00 | 0.0223 | 0.611 | 0.664 | 0.496 |

*Note:* AUC = area under the receiver operating characteristic curve. Sensitivity and specificity values correspond to the final selected LASSO logistic regression model for each outcome (based on the highest AUC). λ = regularization parameter; α = mixing parameter (LASSO = 1, Ridge = 0, Elastic Net = $0 < \alpha < 1$).



| Number | Variable Label |
|---|---|
| 1 | Life satisfaction |
| 2 | Emotional support |
| 3 | Loneliness |
| 4 | Employment status |
| 5 | Food insecurity |
| 6 | Receiving food assistance |
| 7 | Difficulty paying bills |
| 8 | Loss of or threatened loss of utility services |
| 9 | Transportation barriers |
| 10 | Stress |

| Number | Variable Label |
|---|---|
| 11 | Heart attack |
| 12 | Angina or coronary heart disease |
| 13 | Stroke |
| 14 | Asthma |
| 15 | Skin cancer |
| 16 | Melanoma or other cancer |
| 17 | C.O.P.D., emphysema or chronic bronchitis |
| 18 | Depression |
| 19 | Kidney disease |
| 20 | Arthritis, rheumatoid arthritis, gout, lupus, or fibromyalgia |
| 21 | Diabetes |
| 22 | Alcohol use |
| 23 | Tobacco smoking |
| 24 | E-cigarette use |

**Figure 2.1** Tetrachoric Correlations Among SDOH and Health Outcomes

*Note:* C.O.P.D = Chronic Obstructive Pulmonary Disorder

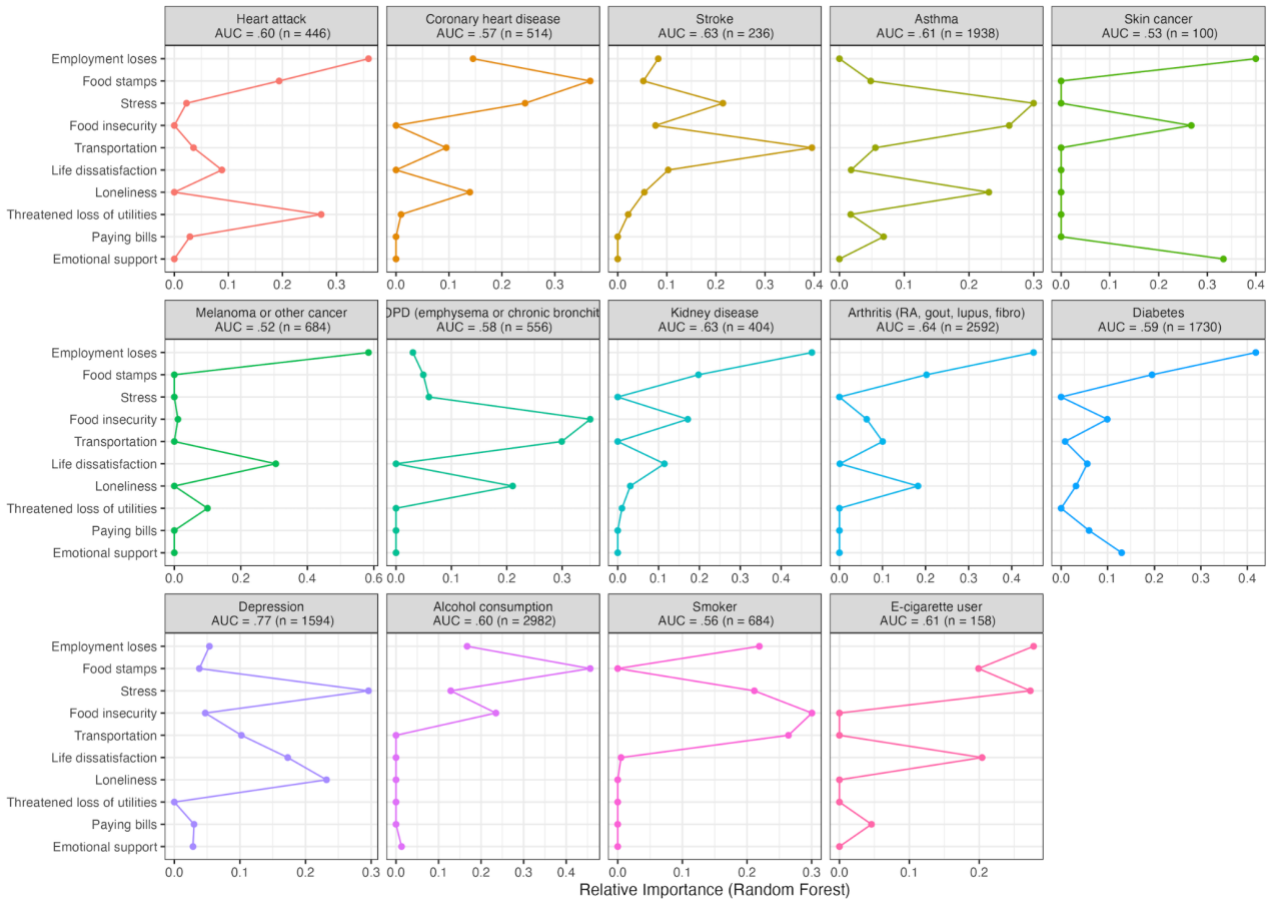



**Figure 2.2** Elastic Net Variable Importance for Classifying Health Outcomes from SDOH

## Supplemental Tables

**Supplemental Table 2.1** Unimputed SDOH, Chronic Disorders, and Indicators of Wellbeing and Behavioral Health

| Variables | Mean/Count (SD/%) ($n$ = 4,594) |
|---|---|
| **Age** | |
| 18-24 | 280 (6.1%) |
| 25-34 | 638 (13.9%) |
| 35-44 | 676 (14.7%) |
| 45-54 | 844 (18.4%) |
| 55-64 | 919 (20%) |
| 65+ | 1237 (26.9%) |
| **Sex** | |
| Male | 1722 (37.5%) |
| Female | 2872 (62.5%) |
| **Race/ethnicity** | |
| Hispanic | 4544 (98.9%) |
| White | 28 (0.6%) |
| Black | 10 (0.2%) |
| Multiple | 1 (0%) |
| Other | 2 (0%) |
| **Education** | |
| Less than high school | 513 (11.2%) |
| High school | 1132 (24.6%) |
| Some college/tech | 1229 (26.8%) |
| College/tech | 1708 (37.2%) |
| **Income** | |
| < 15,000 | 1026 (22.3%) |
| 15,000-<25,000 | 908 (19.8%) |
| 25,000-<35,000 | 606 (13.2%) |
| 35,000-<50,000 | 545 (11.9%) |
| 50,000-<100,000 | 440 (9.6%) |
| 100,000-<200,000 | 123 (2.7%) |
| 200,000+ | 37 (0.8%) |
| **SDOH** | |
| Life dissatisfaction | 199 (4.3%) |

**Supplemental Table 2.2** Unimputed SDOH, Chronic Disorders, and Indicators of Wellbeing and Behavioral Health (Continued)

| | |
|---|---|
| Emotional support | 763 (16.6%) |
| Loneliness | 1588 (34.6%) |
| Employment loses | 462 (10.1%) |
| Food stamps | 1992 (43.4%) |
| Food insecurity | 999 (21.7%) |
| Paying bills | 674 (14.7%) |
| Threatened loss of utilities | 363 (7.9%) |
| Transportation | 483 (10.5%) |
| Stress | 927 (20.2%) |
| **Chronic disorders** | |
| Heart attack | 223 (4.9%) |
| Angina or coronary heart disease | 255 (5.6%) |
| Stroke | 118 (2.6%) |
| Asthma | 967 (21%) |
| Skin cancer | 50 (1.1%) |
| Melanoma | 342 (7.4%) |
| COPD, emphysema, or chronic bronchitis | 278 (6.1%) |
| Depression | 795 (17.3%) |
| Kidney disease | 201 (4.4%) |
| Arthritis, rheumatoid arthritis, gout, lupus, or fibromyalgia | 1284 (27.9%) |
| Diabetes | 863 (18.8%) |
| **Wellbeing and behavioral health** | |
| Alcohol use | 1456 (31.7%) |
| Tobacco use | 341 (7.4%) |
| Electronic cigarette use | 78 (1.7%) |

*Notes:* SDOH = Social determinants of health.

# Chapter IV

## Vidas en Contexto: Unpacking Social Determinants of Health and Related Health Outcomes among Puerto Ricans through a Person-centered Approach

## Abstract

**Background.** Social Determinants of Health (SDOH) are among the most significant predictors of health outcomes, often outweighing the effects of medical care and genetic predisposition. Research on SDOH among Puerto Ricans residing on the island reveals interactions of historical, socio-political, economic, and environmental factors contributing to persistent health disparities. This study used a person-centered latent class analysis to explore the SDOH and the distinct patterns of unmet social needs within the Puerto Rican population.

**Methods.** Data were drawn from the 2023 Behavioral Risk Factor Surveillance System survey conducted by the CDC. The sample included respondents who completed the survey and reside in Puerto Rico (n = 4,594). A majority of the sample were aged 65 and older (26.9%). Latent class analyses were used to identify SDOH clusters, while descriptive statistics and logistic regression analyses were performed to examine various health correlates.

**Results.** SDOH was best represented by four latent classes: Material Scarcity, Unmet Support and Stress, Low Needs, and General Unmet Needs. Demographic characteristics, in addition to risks for negative health outcomes, varied significantly across the four classes. Behavioral and emotional health risks varied significantly across the four classes. General Unmet Needs, Material Scarcity, and Stress classes showed elevated health risks compared to the Low Needs group, with the General Unmet Needs class exhibiting the highest risk overall.

**Conclusion.** This study provided insights into patterns of SDOH classes in this population. Specifically, how demographic and socioeconomic characteristics vary across classes and correspond with different burdens of chronic conditions and behavioral health. Targeting distinct SDOH classes will enable precise allocation of resources, tailored screening, and intervention efforts aimed at alleviating health disadvantages in Puerto Rico.

## Introduction

The social determinants of health (SDOH) are non-medical factors shaping individual and population health outcomes. SDOH encompasses the conditions in which people are born, grow, work, live, and age, as well as the broader set of forces and systems—such as economic policies, social norms, and political systems—influencing these circumstances (World Health Organization). These determinants include economic stability, access to quality education and healthcare, neighborhood and built environment, and social and community context (Healthy People 2030). The interplay of these factors can promote health or perpetuate inequities across different populations.

Prior research indicates that SDOH are among the most significant predictors of health outcomes, often outweighing the effects of medical care and genetic predisposition (Braveman & Gottlieb, 2014; Chelak & Chakole, 2023). For instance, socioeconomic status is consistently associated with disparities in morbidity and mortality. Individuals with lower income or educational attainment have an increased likelihood of experiencing worse health outcomes, such as increased disability, functional limitations, and higher mortality rates (Braveman & Gottlieb, 2014; Chelak & Chakole, 2023). Furthermore, the impact of SDOH on chronic health conditions is well-documented. A systematic review outlined how patients with heart failure who experienced adverse social determinants such as housing instability, food insecurity, and lack of transportation had significantly worse clinical outcomes, including higher rates of hospitalization and mortality (Enard et al., 2023).

Mental health and substance use are also associated with SDOH. Social isolation, discrimination, lack of supportive community networks, and unemployment have been identified as key contributors to depression, anxiety, and suicidality (Na et al., 2025; Trujillo et al., 2017;

Vu et al., 2019; Yelton et al., 2022). Furthermore, communities facing economic hardships or social marginalization often experience higher rates of substance use disorders, driven by both environmental stressors and reduced access to prevention and treatment services (Galea & Vlahov, 2002; Lin et al., 2024).

While SDOH has been shown to impact all populations, it might have an increased effect on certain locations or populations, such as individuals living in Puerto Rico (Adler et al., 2016; Lafarga Previdi & Vélez Vega, 2020). Research examining SDOH among Puerto Ricans residing on the island reveals interactions of historical, socio-political, economic, and environmental factors contributing to persistent health disparities on the island (Lafarga Previdi & Vélez Vega, 2020). Prior research has highlighted how these disparities are deeply rooted in Puerto Rico's colonial status and political subordination to the United States, which structurally constrains access to economic resources, healthcare funding, and social protections (McSorley et al., 2024). Researchers argue that colonialism itself functions as a fundamental SDOH in Puerto Rico, shaping living conditions, economic opportunities, and access to care in ways that perpetuate inequities (Martin & Pace, 2025; McSorley et al., 2024).

Lafarga Previdi and Vélez Vega (2020) adapted the National Institute of Minority Health and Health Disparities (NIMHD) framework to Puerto Rico's unique context, demonstrating how structural conditions—characterized by poverty affecting over 40% of the population, median household income substantially below the U.S. average, deficient infrastructure, and a fragile healthcare system—drive higher prevalence and mortality rates of chronic diseases such as diabetes, asthma, and cardiovascular disease compared to the mainland United States. Building on this adaptation, the present study utilizes the NIMHD Framework as its guiding model to comprehensively examine how intersecting behavioral, socio-economic, and environmental

factors shape health outcomes among Puerto Ricans residing on the island. Within the NIMHD's behavioral domain, adverse social conditions are linked to risky health behaviors, such as smoking and binge drinking, which often serve as coping mechanisms in response to chronic stress and recurring disasters (National Institute of Minority Health and Health Disparities, 2025). Additionally, research findings have established that poor health-related quality of life (HRQoL) among Puerto Rican adults is strongly associated with multiple chronic conditions, advanced age, and low income, with no significant improvement over the past decade (Frontera-Escudero et al., 2023). The contextual reality of Puerto Rico has been further complicated by a series of devastating natural and public health crises in recent years. The catastrophic impact of Hurricanes Irma and Maria in 2017 exposed and worsened long-standing vulnerabilities in infrastructure, healthcare access, and social services, leading to increased morbidity and mortality and highlighting the island's limited disaster preparedness (Guerra Vélazquez, 2022). Subsequent earthquakes in 2019 and 2020 have compounded these challenges by disproportionately affecting isolated and marginalized communities in addition to straining an already fragile healthcare system (Peña-Vargas et al., 2022). These events have intensified social determinants such as housing instability, food insecurity, and limited access to basic services and transportation.

Research specifically focused on SDOH in Puerto Rico remains limited and fragmented. Most existing studies concentrate on individual-level risk factors or analyze one specific SDOH at a time (Lafarga Previdi & Vélez Vega, 2020). The Puerto Rico Observational Study of Psychosocial, Environmental, and Chronic Disease Trends (PROSPECT), currently the largest epidemiological study in Puerto Rico, examines multiple psychosocial, environmental, and biological risk factors simultaneously to understand these interactions, but results are still

emerging (Mattei et al., 2021). Importantly, no published research to date has thoroughly investigated the combined effects of multiple SDOH domains and their relation to broad health outcomes within Puerto Rico's socio-cultural and political context. This highlights a pressing need for culturally tailored, multi-level research approaches that address the diverse interactions of these social determinants to inform island-wide prevention and intervention programs.

**Person-Centered Analytic Approaches to SDOH**

Life course theory provides a framework to understand how SDOH can influence health outcomes by shaping risk exposures over time and emphasizing the role of contextual factors that might increase risk among groups of people affected by social inequities (i.e., marginalized groups; Ben-Shlomo & Kuh, 2002; Kuh et al., 2003). Life course theory also suggests that risk factors or exposures (e.g., SDOH) can either exert their effects individually, cumulatively (i.e., through their aggregate impact), or in combination (i.e., risk clustering), which can lead to differential health outcomes among individuals (Kuh et al., 2003). Indeed, prior research on SDOH has found that most people tend to experience multiple SDOH rather than experiencing one SDOH independently, and suggested that understanding the interactions of these SDOH would better inform tailored intervention efforts (Schiltz et al., 2022). Furthermore, prior research has documented social inequities, with individuals holding marginalized identities (e.g., Black, lower income) being more likely to experience combinations of multiple SDOH. Statistical approaches, such as Latent Class Analysis (LCA) or Latent Profile Analysis (LPA), provide a method to examine how unique combinations of risk factors cluster together and influence health outcomes. Specifically, LCA is useful for identifying heterogeneity within the study sample by grouping individuals who share similar profiles of SDOH (Saunders et al., 2020). However, limited studies have utilized this approach to assess SDOH, especially among

particularly vulnerable populations such as Puerto Ricans, despite research previously showing that SDOH tend to co-occur and can have implications for tailored treatment interventions.

Recent research has increasingly employed person-centered analyses (e.g., LCA and LPA) to examine shared patterns of SDOH that co-occur among individuals. For example, a study using LCA to examine SDOH among Black individuals in the U.S. identified four classes: (a) many unmet needs, (b) basic unmet needs (i.e., unemployment, food and utility insecurity, food stamp assistance), (c) unmet healthcare needs (e.g., dental care, medications, delayed medical care), and (d) few unmet needs (Suzuki et al., 2024). These findings underscore the importance of exploring variability in the co-occurrence of SDOH, given the diverse combinations of SDOH that people might experience. However, this study did not examine how these classes were associated with health outcomes, which could help highlight potential health disparities based on differing experienced SDOH. Other studies that have assessed health and mental health outcomes have identified similar classes. For instance, McCarthy et al. (2021) found four classes of SDOH among a cohort of Medicaid beneficiaries in the District of Columbia: (a) low risk, (b) financial strain and housing instability, (c) mostly unemployed with limited car and internet access, and (d) high social risk (e.g., loneliness) and unemployment. This study found that the low-risk class reported the most favorable health and mental health outcomes, while the high social risk and unemployment class experienced the poorest outcomes.

While researchers have highlighted how colonialism, economic instability, and environmental factors contribute to health disparities in Puerto Rico, a critical research gap remains: no studies have used a person-centered approach to analyze the co-occurrence of SDOH among residents. (Lafarga Previdi & Vélez Vega, 2020). There is also limited research assessing the potential relationship between classes of SDOH and demographic factors, such as

race/ethnicity, which could help identify factors driving health disparities. Research that has examined differences in SDOH classes based on race/ethnicity has found significant differences, with White individuals being more likely to be in a class with fewer SDOH as compared to People of Color (e.g., Black, Indigenous; Shokoohi et al., 2019). Thus, there is a need for research to apply person-centered approaches to better understand the nuanced ways in which SDOH co-occur among individuals and influence health and mental outcomes, especially among Puerto Ricans living in Puerto Rico, given their unique colonial history, economic precarity, and environmental vulnerabilities, which may contribute to health disparities observed in the island (Lafarga Previdi & Vélez Vega, 2020). The present study aimed to bridge this knowledge gap by uncovering clusters of unmet SDOH needs and related health outcomes among Puerto Rican adults. The specific aims of the present study were (a) to identify associations between SDOH and health outcomes, (b) to use a person-centered approach to identify SDOH classes, and (c) to explore correlations with demographic characteristics and health outcomes. We hypothesized that greater unmet SDOH would be generally related to poorer health outcomes (Braveman & Gottlieb, 2014; Chelak & Chakole, 2023). Based on prior research, we expected to find classes related to low needs, material scarcity, and high needs (McCarthy et al., 2021; Suzuki et al., 2024). The SDOH profile associated with low needs was expected to have lower odds of reporting negative health outcomes.

## Methods

Data for this study were drawn from the 2023 Behavioral Risk Factor Surveillance System (BRFSS), a nationally-representative, cross-sectional health survey conducted annually by the Centers for Disease Control and Prevention (CDC) that monitors health-related risk behaviors, chronic health conditions, and use of preventive services among adults aged 18 and

older in the United States and U.S. territories (Centers for Disease Control and Prevention, 2024). For this study, the data were analyzed for a subsample of respondents who completed the 2023 BRFSS and indicated residing in Puerto Rico (n = 4,594). The data were collected between July - December 2023 using a standardized survey administered via computer-assisted telephone interviews (CATI). Respondents were contacted through random-digit dialing on both landlines and cell phones. Prior to participation, verbal informed consent was obtained, and all respondents were informed that their participation was voluntary and that they could skip questions or end the interview at any time. The CATI system ensured consistent delivery of questions and real-time data entry across interviews (Centers for Disease Control and Prevention, 2024). Participants provided verbal informed consent prior to completing the survey, were told that identifying information would be kept confidential, and were informed that completing the survey was voluntary and that they could discontinue at any time. The University of Tennessee, Knoxville Institutional Review Board approved secondary analyses of the 2023 BRFSS data as being non-human subjects research. Unimputed values of participants' demographic characteristics are described in Supplemental Table 3.1.

## Measures

### *Demographics*

Participants reported their age, sex, race/ethnicity, annual household income, and educational attainment. Age was categorized into six groups: 18-24, 25-34, 35-44, 45-54, 55-64, and 65 years or older. Sex was coded as male or female. Race and ethnicity were reported into the following categories: White, Black or African American, Hispanic or Latino, Asian, Native Hawaiian or Other Pacific Islander, American Indian or Alaska Native, Mixed Race, or Other. Household income was assessed by asking respondents to report their total annual income using

the following seven categories: <$15,000, $15,000 to <$25,000, $25,000 to <$35,000, $35,000 to <$50,000, $50,000 to <$100,000, $100,000 to <$200,000, and $200,000 or more. Educational attainment was assessed and categorized into the following categories: did not graduate high school, high school graduate or equivalent, some college or technical school, and graduated from a college or technical school.

***SDOH***

Participants responded to 10 items representing social stressors or vulnerabilities related to the SDOH. These included life dissatisfaction, lack of emotional support, loneliness, employment loss, food insecurity, use of food stamps, difficulty paying bills, threatened loss of utilities due to lack of payment, lack of transportation, and perceived stress. Each variable was binary (0 = No, 1 = Yes) and all items were summed to create a cumulative SDOH burden score (range = 0 to 10), with higher scores indicating greater exposure to adverse social conditions. These indicators reflect multidimensional aspects of social vulnerability, including economic instability, social isolation, and unmet material needs.

***Chronic Health Conditions***

Participants self-reported whether they had ever been told by a health professional that they had any of several chronic conditions, including cardiovascular disease (heart attack, angina, or stroke), respiratory conditions (asthma or chronic obstructive pulmonary disease), diabetes, arthritis, kidney disease, depression, and various forms of cancer. Responses were binary (0 = No, 1 = Yes) and all items were summed to form a cumulative chronic health condition score (range = 0 to 12). This variable was used to reflect overall chronic disease burden.

### *Well-being and Behavioral Health*

Self-rated physical and mental health were measured with two continuous items asking participants to rate their health on a scale based on the number of days in the past 30 during which their health was “not good”. Higher values on these measures indicate poorer perceived health. Behavioral health variables included past-month alcohol consumption, cigarette smoking, and electronic cigarette use, each measured dichotomously (0 = No, 1 = Yes).

## Analytic Plan

All analyses were conducted in R (version 4.5.0; R Core Team, 2025) and R Studio (version 2024.12.1+563; R Studio Team, 2024) with the poLCAExtra (Caron, 2025), mice (van Buuren & Groothuis-Oudshoorn, 2011), psych (Revelle, 2024), furniture (Barrett, 2023), tidyverse (Wickham et al., 2019), and ggstats packages (Patil, 2021). Within the present sample, 1.8% of all possible responses on study variables of interest were missing. The most common pattern was 23.6% participants missing responses on one variable (predominantly on the income variable). The pattern of missingness was frequently significantly related to variables of interest, with respondents reporting higher risk categories for SDOH and outcome variables being largely more likely to have missing data. Thus, data were treated as being Not Missing at Random (MNAR). Descriptive statistics were calculated using the appropriate test for the variable type (i.e., Kruskal-Wallis test, chi-square test). Latent class analysis (LCA) was used to identify subgroups of individuals with similar patterns of SDOH needs (Lanza & Rhoades, 2013). We fitted two to nine potential classes for LCA to determine the optimal fit (Weller et al., 2020). Model selection was based on relative fit indices (Bayesian Information Criterion [BIC], Akaike Information Criterion [AIC], log likelihood), entropy, and interpretability. Lower BIC, AIC, and log likelihood values indicate better model fit, while entropy values closer to 1.0 suggested

higher classification precision (Hu & Bentler, 1999; Weller et al., 2020). Bootstrapped likelihood ratio test (BLRT) with 1,000 iterations were used to compare model fit between number of classes, which signals whether the model fit for a more complex model significantly differed from the subsequent simpler model (Lanza & Rhoades, 2013). In selecting the optimal number of classes, we did not consider solutions that contained less than 5% of the sample, as this can contribute to instability in findings (Weller et al., 2020).

Differences in demographics, cumulative chronic conditions, and perceived health across classes were assessed using Chi-square tests and Kendall's Tau bivariate correlations. To explore predictors of chronic diseases, logistic regression models were conducted with an indicator representing latent class membership. Odds ratios (ORs) and 95% confidence intervals (CIs) were computed for each predictor, using the low-risk class as the reference group. Lastly, we conducted variable importance analyses to identify which SDOH indicators were most influential in distinguishing between latent classes.

## Results

### Descriptives

On average, participants reported 1.88 (SD = 1.80) unmet SDOH needs (Table 3.3). The most commonly reported SDOH-related needs were receipt of food stamps, experiencing loneliness, and food insecurity. In contrast, the least commonly reported needs included life dissatisfaction, threatened loss of utilities, and transportation difficulties. Participants reported an average of 1.17 (SD = 1.35) chronic health conditions. The most prevalent chronic conditions included arthritis, rheumatoid arthritis, gout, lupus, or fibromyalgia, asthma, and diabetes. Less frequently reported conditions included kidney disease, stroke, and skin cancer. Regarding behavioral and emotional wellbeing, participants reported a mean of 5.78 days (SD = 9.98) in the

past 30 days where their physical health was not good, and a mean of 4.06 days (SD = 8.82) when their mental health was not good. In terms of substance use, 32.5% reported alcohol use, 7.4% reported tobacco use, and 1.7% reported use of electronic cigarettes. See Supplemental Table 3.1 for unimputed frequencies of SDOH, chronic disorder, and indicators of wellbeing and behavioral health.

**Latent Class Analysis**

Values for the BIC, AIC, and log likelihood generally decreased with the addition of each latent class with added complexity improving model fit across fit indices until the four-class model (Table 3.1). The BLRT test suggests that model fit did not significantly improve beyond the five-class model ($p < .005$). While entropy peaked at .749 for the three-class model, the added complexity of the four-class model appeared to be justified by general lower values across fit indices and significant BLRT test (AIC = 36969.10, BIC = 47145.69, $p < .001$). After the four-class model, AIC and log likelihood values continue to decrease with increased complexity but BIC displayed the opposite trend. While the five-class model offered slightly better entropy, the four-class model was selected as it provided a better balance between model fit and entropy. See Table 1 for LCA fit statistics.

**SDOH Class Descriptives**

A four-class model identified cultures mapping on to (1) Material Scarcity (n = 798), characterized by high levels of economic hardship such as food insecurity, difficulty paying bills, and utility shutoffs; (2) Unmet Support and Stress (n = 701), defined by elevated emotional distress, including lack of emotional support, loneliness, and stress; (3) Low Needs (n = 2,856), a low-risk group with minimal SDOH challenges across domains; and (4) General Unmet Needs (n

= 239), comprising individuals who reported high levels of both material and psychosocial burdens, including food insecurity, difficulty paying bills, stress, and loneliness.

Subsequent univariate analysis suggests that demographic characteristics varied significantly across the four SDOH classes (Table 3.2). Participants in the low needs category were the oldest and more likely to be males relative to the other classes ($p < .001$). Income disparities were statistically significant ($p < .001$), with nearly half of the General Unmet Needs group earning less than $15,000 annually, compared to 21.1% of the Low Needs group. Education also differed by class ($p < .001$); only 26.4% of the General Unmet Needs group held a college or technical degree, versus 40.9% of those in the Low Needs class. Racial and ethnic composition did not differ significantly across classes ($p = .794$), with the majority of the sample identifying as Hispanic.

Cumulative SDOH burden differed significantly by class ($p < .001$), with mean scores ranging from 0.78 (SD = 0.74) in the Low Needs group to 6.32 (SD = 1.18) in the General Unmet Needs class (Table 3.3). Individual SDOH indicators generally differed across classes ($p < .001$). The General Unmet Needs group consistently reported the highest prevalence across nearly all SDOH domains, including life dissatisfaction ($n$ = 51 (21.3%)), lack of emotional support ($n$ = 145 (60.7%)), loneliness ($n$ = 225 (94.1%)), food stamp usage ($n$ = 151 (63.2%)), food insecurity ($n$ = 187 (78.2%)), employment loss ($n$ = 85 (35.6%)), threatened loss of utilities ($n$ = 130 (54.4%)), transportation barriers ($n$ = 116 (48.5%)), difficulty paying bills ($n$ = 208 (87%)), and high stress ($n$ = 212 (88.7%)). In contrast, participants in the Low Needs class reported the lowest rates across all indicators.

The number of chronic health conditions varied significantly across classes. Mean cumulative chronic condition scores ranged from 0.94 (SD = 1.16) in the Low Needs class to

2.02 (SD = 1.60) in the General Unmet Needs group ($p < .001$; See Table 3). Across individual conditions, significant class differences ($p < .05$) were observed for heart attack, angina or coronary heart disease, stroke, asthma, chronic obstructive pulmonary disease (COPD), depression, kidney disease, arthritis or related conditions, and diabetes. Depression was elevated in the General Unmet Needs and Unmet Support and Stress classes in comparison to the Low Needs group ($p < .001$). Asthma prevalence ranged from 16.4% in the Low Needs class to 38.9% in the General Unmet Needs class ($p < .001$), and COPD was reported by 13.8% of the General Unmet Needs group compared to 4.4% of the Low Needs group ($p < .001$). Stroke, kidney disease, and arthritis also followed this pattern of increased burden in higher-need groups.

Behavioral and emotional health indicators differed significantly across classes. Participants in the General Unmet Needs class reported significantly more days of poor physical (M = 11.23, SD = 12.35) and mental health (M = 13.48, SD = 12.90) in the past 30 days than those in the Low Needs class (M = 4.20, SD = 8.59 and M = 1.77, SD = 5.68, respectively; $p < .001$; See Table 3). Perceived health worsened with increasing SDOH burden across all classes. Tobacco use was significantly higher in the General Unmet Needs group compared to the Low Needs class ($p < .001$), and electronic cigarette use was also higher in the General Unmet Needs group relative to the Low Needs group ($p = .005$). Alcohol use was significantly associated with class membership ($p = .019$), although the differences were less pronounced.

**Logistic Regression**

Compared to the Low Needs group, individuals in the General Unmet Needs class had significantly greater odds ($p < .05$) of reporting most chronic health conditions and substance use, with the exception of skin cancer, melanoma, respiratory disorders, diabetes, and alcohol use. Participants in the Material Scarcity class were at greater risk for reporting asthma,

respiratory disorders, depression, kidney disease, autoimmune diseases, diabetes, and tobacco and e-cigarette use relative to the Low Needs class ($p < .05$). Members of the Material Scarcity class were at lower risk for reporting alcohol use relative to those in the Low Needs class ($p < .05$). Lastly, members of the Unmeet Support and Stress class were at higher risk for reporting all chronic health conditions and indicators of wellness/behavioral health ($p < .05$) with the exception of skin cancer, melanoma, and alcohol use. See Figure 2 for logistic regression analyses.

## Discussion

This study expands the literature by identifying distinct patterns of unmet social needs among adults in Puerto Rico and demonstrating that these patterns correspond to meaningful differences in health outcomes. Rather than treating social determinants as isolated risk factors, the findings show that material hardship and psychosocial stress frequently co-occur in specific combinations within the population. Individuals experiencing multiple overlapping social vulnerabilities—particularly those characterized by both economic hardship and limited social support—reported substantially worse chronic and behavioral health outcomes. These findings suggest that health disparities in Puerto Rico are shaped not only by individual social risks, but by clusters of disadvantage, highlighting the need for targeted public health strategies that address the specific combinations of material and psychosocial challenges experienced by different subgroups. Both unmet SDOH needs and chronic health conditions were common in the sample, with cumulative SDOH scores positively associated with higher comorbidity of chronic diseases. The SDOH were best represented by four latent classes representing: (1) Material Scarcity, characterized by economic hardship such as food insecurity and difficulty paying bills; (2) Unmet Support and Stress, marked by elevated emotional distress including loneliness and

lack of emotional support; (3) Low Needs, which exhibited minimal social challenges and consisted of older, more socioeconomically advantaged individuals; and (4) General Unmet Needs, which are individuals facing high levels of both material and psychosocial adversities. These classes were differentially associated with health outcomes, emphasizing the importance of considering person-centered patterns of social needs.

Unmet SDOH needs and chronic health conditions are common experiences among Puerto Rican adults. Our findings suggest that Puerto Ricans reported nearly two unmet SDOH needs on average, with the most being receipt of food stamps, experiencing loneliness, and food insecurity. These findings align with prior research documenting significant socioeconomic challenges in Puerto Rico, such as high poverty rates and widespread food insecurity, which contribute to unmet social needs and elevate chronic disease risk (Frontera-Escudero et al., 2023). Participants also commonly reported experiencing approximately one chronic health condition on average, with the most prevalent conditions including arthritis, rheumatoid arthritis, gout, lupus, or fibromyalgia, asthma, and diabetes. Participants reported a few days with poor physical and mental health, which suggest positive perceptions of well-being on average. Rates of substance use were relatively low, with alcohol being the highest frequency, followed by tobacco and e-cigarette use. The observed prevalence of comorbidity suggests potential systemic healthcare barriers and socioeconomic adversity widely reported in this population (Frontera-Escudero et al., 2023). The positive perceptions of well-being among participants may be influenced by cultural factors or adaptive coping mechanisms, as suggested in prior research (Lafarga Previdi & Vélez Vega, 2020). The low rates of substance use suggest further investigation is needed to understand if there are other cultural or social determinants explaining these findings.

**Latent classes**

Our analyses of SDOH clusters suggest that a four-class model provided the best balance between model fit, entropy, and incremental informational contribution of considering additional profiles. The four-class model was composed of SDOH clusters mapping onto (1) Material Scarcity (i.e., high levels of economic hardship and resource scarcity), (2) Unmet Support and Stress (i.e., elevated distress, loneliness, and lack of emotional support), (3) Low Needs (i.e., minimal SDOH challenges), and (4) General Unmet Needs (i.e., high levels of need). LCA has been previously used to identify distinct social risk profiles from SDOH data. Prior studies have commonly found clusters similar to those uncovered by the present study, ranging from low to high social risk profiles with varying levels of employment status and resource access (McCarthy et al., 2021). Our findings extend this work by uncovering hidden subgroups with unique combinations of social challenges within the Puerto Rican context that are shaped by its colonial history (Martin & Pace, 2025; McSorley et al., 2024).

At the same time, the present study cannot directly determine whether the patterns identified differ meaningfully from those observed among mainland Puerto Ricans or other U.S. populations, as comparable analyses using identical measures were not conducted. As a result, it remains unclear whether the latent subgroups observed here reflect unique features of the Puerto Rican social context or broader patterns of social vulnerability that occur across diverse populations. Future research comparing Puerto Rican residents with mainland Puerto Rican and non-Puerto Rican populations using standardized measures of SDOH would help clarify whether distinct social risk profiles emerge across these contexts and how structural conditions shape their health consequences.

Demographic characteristics differed significantly across the four SDOH classes, with the Low Needs group tending to be older males, while the General Unmet Needs group was disproportionately characterized by lower income and educational attainment. This highlights the importance of targeted interventions for lower-income individuals who face numerous material and psychosocial challenges despite similar racial and ethnic backgrounds. Considering these subgroup differences is essential as they likely contribute to variability in health outcomes.

Risk for negative health outcomes varied notably across the identified SDOH classes, with the General Unmet Needs class showing higher burdens of multiple chronic conditions compared to the Low Needs group. Significant differences were observed in cardiovascular diseases, respiratory illnesses, depression, kidney disease, arthritis, and diabetes, with depression and respiratory conditions such as asthma and COPD particularly high among those facing greater social adversity. Given that SDOH have been generally linked to poor health outcomes (Braveman & Gottlieb, 2014; Chelak & Chakole, 2023) and our findings suggest that this relationship may have configurational nuances. This emphasizes the importance of recognizing distinct social risk profiles, as variation in unmet social needs may contribute to disparities in chronic disease prevalence and overall health status.

Behavioral and emotional health risks varied significantly across the SDOH classes, with those in the General Unmet Needs class reporting more days of poor physical and mental health compared to the Low Needs group. Furthermore, higher tobacco and e-cigarette use was reported in the General Unmet Needs group in comparison to the Low Needs group highlighting group differences. Notably, perceived health worsened with increasing SDOH burden across all four classes and alcohol use was significantly associated with class membership despite having less pronounced group differences. Social conditions are known to impact substance use as a coping

mechanism and negatively impact mental health (Amaro et al., 2019; National Institute of Minority Health and Health Disparities, 2025). Our findings highlight different patterns of behavioral health associated with SODH profiles.

Most SDOH classes exhibited a higher risk for negative health outcomes compared to the Low Needs class. Individuals in the General Unmet Needs group had significantly increased odds of reporting a wide range of chronic conditions and substance use, reflecting compounded material and psychosocial adversity. Those in the Material Scarcity class were more likely to report respiratory conditions, depression, kidney and autoimmune diseases, diabetes, and higher tobacco and e-cigarette use, but lower alcohol use, suggesting distinct behavioral patterns tied to economic hardship. The Unmet Support and Stress class showed elevated risk across most chronic conditions and behavioral health indicators, highlighting the influence of psychosocial stressors and social isolation. These differences align with prior work emphasizing how socioeconomic disadvantage, limited access to resources, and psychosocial stress operate together to worsen health outcomes (World Health Organization, n.d.). Variation in demographic and socioeconomic factors between classes may explain differences in exposure and resilience to these health risks.

An unexpected finding in our study was the pattern of alcohol use across the SDOH subgroups. While substance use generally increased with rising social needs, alcohol use was lower in the Material Scarcity class compared to the Low Needs class. This result aligns with the well-documented “alcohol harm paradox” where individuals in lower socioeconomic positions often consume equal or less alcohol than higher SES groups but suffer disproportionately greater alcohol-related harms (Boyd et al., 2021). Possible explanations include differences in drinking patterns, such as binge drinking or episodic heavy drinking, interactions with other health

behaviors and stressors, and barriers to healthcare services (Beard et al., 2016). Future research should examine drinking patterns, stress-related coping behaviors, and access to care across SDOH subtypes to clarify mechanisms underlying alcohol-related health risks. Particularly, how these might increase risk differential based on class subtype.

**Implications**

The results from this study provide important insights into patterns of SDOH classes within the Puerto Rican population, in particular the distinct subgroups characterized by material scarcity, psychosocial stress, and generalized unmet needs, and low needs. This suggests that health risks are not uniformly distributed but are influenced by the interaction of structural, material, and psychosocial factors. This is consistent with current public health frameworks recognizing social determinants such as poverty, education, social isolation, and resource access as fundamental drivers of health disparities beyond individual biology of healthcare access. The unexpected pattern of alcohol use, which was lower among individuals experiencing greater material hardship despite overall increased health risks, further demonstrates the complexity of these associations. These finding challenges assumptions that alcohol consumption and outcomes associations are simplistic, but rather, require context-specific research into the behavioral and social mechanisms underlying health inequities within SDOH subtypes. These results emphasize the need for integrated, multisectoral public health strategies that address both material deprivation (e.g., food insecurity, economic strain) and psychosocial adversity (e.g., loneliness, stress). Recognizing and targeting distinct SDOH profiles will enable more precise allocation of resources, tailored screening, and intervention efforts aimed at alleviating compounding health disadvantages in vulnerable populations, including Puerto Rican adults. Furthermore, the application of advanced analytical techniques like latent class analysis in social epidemiology

can facilitate the identification of hidden social risk patterns, ultimately informing policies and practices that intervene on upstream determinants rather than solely managing downstream health outcomes.

By advancing understanding of the multifaceted nature of social risk and its health impacts, this work contributes to a growing shift toward comprehensive, equity-focused public health approaches. The financial challenges faced by Puerto Rico are deeply rooted in its colonial relationship with the United States (Martin & Pace, 2025; McSorley et al., 2024). This colonial legacy, compounded by the Jones Act maritime law, a federal statute requiring goods shipped between U.S. ports to be transported on U.S.-flagged ships, significantly inflates costs for essential goods and healthcare supplies, exacerbating economic hardship and limiting access to necessary resources (Hillberry et al., 2024). Natural disasters like Hurricanes Irma and Maria, along with the earthquakes of 2019 and 2020, have further strained the already fragile economy and infrastructure, intensifying poverty and social vulnerability across the island (Guerra Vélazquez, 2022).

Moreover, Puerto Rico faces a persistent “brain drain”, as many professionals and young adults leave the island in search of better economic and educational opportunities on the mainland U.S. (Varas-Díaz et al., 2023). This population outmigration undermines local workforce capacity, including in health and social services, thereby weakening the island’s ability to respond effectively to health crises and provide sustained care (Varas-Díaz et al., 2023). Compounding these structural barriers is Puerto Rico’s limited political representation; as a U.S. territory without voting representation in Congress, the island lacks the political power to advocate for policies that could address these systemic inequities and dismantle restrictive laws that perpetuate economic and health disparities (Political Status of Puerto Rico, 2025).

## Limitations

This study has several limitations that should be considered. First, the cross-sectional design limits the ability to infer causal relationships between SDOH subgroups and health outcomes. As a result, the findings should be interpreted as associative rather than causal, and future longitudinal studies are needed to examine temporal relationships. Second, missing data may have introduced bias that could have influenced class assignment and associations. Because individuals reporting greater social needs were more likely to have incomplete responses, the prevalence of higher-risk social profiles may be slightly underestimated; however, the relatively low overall proportion of missing data and large sample size reduce the likelihood that this substantially altered the observed patterns. Third, the study intentionally focused on adults residing in Puerto Rico to better understand SDOH within this specific social and structural context. While this focus limits generalizability to other U.S. populations, it represents a deliberate design choice given Puerto Rico's unique economic conditions, healthcare infrastructure, and political status, which shape the distribution and impact of social determinants of health.

Additionally, health outcomes were based on self-reported measures, which may be subject to recall bias or misclassification and may not fully capture the clinical severity of chronic conditions. However, self-reported health indicators are widely used in population-based surveillance systems such as the Behavioral Risk Factor Surveillance System and have demonstrated acceptable validity for epidemiologic research. The use of secondary data also limited the ability to tailor SDOH measures specifically to the Puerto Rican context, potentially overlooking nuanced socioeconomic or psychosocial factors. Future research incorporating

culturally specific measures and clinical health indicators would strengthen understanding of SDOH patterns in this population. Despite these limitations, this study provides important insights into patterns of social risk and their associations with chronic, behavioral, and mental health outcomes among adults in Puerto Rico. By identifying distinct SDOH profiles and examining their relationships with health outcomes, the findings contribute to efforts aimed at addressing social and structural drivers of health disparities on the island.

## Conclusions

This study uncovered ways in which various SDOH co–occur and relate to health outcomes among Puerto Ricans. Distinct SDOH classes were identified and characterized through varying degrees of material and psychosocial needs. Their demographic and health correlates were examined and ultimately, these classes emphasize how intersecting factors such as poverty, education, and social support contribute differently to health outcomes, behaviors, and overall quality of life. Our work contributes to the literature by moving beyond single-factor and cumulative analyses to a comprehensive understanding of SDOH patterns in Puerto Rico, an area with limited but critically needed research. These insights are essential for designing targeted interventions addressing the unique social and structural contexts of the island, including the enduring impacts of colonialism, economic challenges, and recent natural disasters.

## References


Adler, N. E., Cutler, D. M., Fielding, J. E., Galea, S., Glymour, M. M., Koh, H. K., & Satcher, D. (2016). Addressing social determinants of health and health disparities: A vital direction for health and health care. *National Academy of Medicine Perspectives*.

Amaro, H., Sanchez, M., Bautista, T., & Cox, R. (2021). Social vulnerabilities for substance use: Stressors, socially toxic environments, and discrimination and racism. Neuropharmacology, 188, 108518. https://doi.org/10.1016/j.neuropharm.2021.108518

Barrett, T. (2023). *furniture: Furniture for quantitative scientists*. R package version 2.3.2. https://CRAN.R-project.org/package=furniture

Beard, E., Brown, J., West, R., Angus, C., Brennan, A., Holmes, J., Kaner, E., Meier, P., & Michie, S. (2016). Deconstructing the Alcohol Harm Paradox: A Population Based Survey of Adults in England. PloS one, 11(9), e0160666. https://doi.org/10.1371/journal.pone.0160666

Ben-Shlomo, Y., & Kuh, D. (2002). A life course approach to chronic disease epidemiology: Conceptual models, empirical challenges and interdisciplinary perspectives. *International Journal of Epidemiology*, *31*(2), 285–293. https://doi.org/10.1093/intjepid/31.2.285

Boyd, J., Bambra, C., Purshouse, R. C., & Holmes, J. (2021). Beyond Behaviour: How Health Inequality Theory Can Enhance Our Understanding of the 'Alcohol-Harm Paradox'. International journal of environmental research and public health, 18(11), 6025. https://doi.org/10.3390/ijerph18116025

Braveman, P., & Gottlieb, L. (2014). The social determinants of health: it's time to consider the

causes of the causes. Public health reports (Washington, D.C. : 1974), 129 Suppl 2(Suppl 2), 19–31. https://doi.org/10.1177/00333549141291S206

Caron, P. (2025). poLCAExtra: New and Convenient Functions for the Package 'poLCA'. R package version 0.1. https://github.com/quantmeth/poLCAExtra

Centers for Disease Control and Prevention. (2024, February 9). Behavioral Risk Factor Surveillance System (BRFSS). U.S. Department of Health and Human Services. https://www.cdc.gov/brfss/index.html

Chelak, K., & Chakole, S. (2023). The Role of Social Determinants of Health in Promoting Health Equality: A Narrative Review. Cureus, 15(1), e33425. https://doi.org/10.7759/cureus.33425

Enard, K. R., Coleman, A. M., Yakubu, R. A., Butcher, B. C., Tao, D., & Hauptman, P. J. (2023). Influence of Social Determinants of Health on Heart Failure Outcomes: A Systematic Review. Journal of the American Heart Association, 12(3), e026590. https://doi.org/10.1161/JAHA.122.026590

Frontera-Escudero, I., Bartolomei, J. A., Rodríguez-Putnam, A., & Claudio, L. (2023). Sociodemographic and health risk factors associated with health-related quality of life among adults living in Puerto Rico in 2019: a cross-sectional study. BMC public health, 23(1), 2150. https://doi.org/10.1186/s12889-023-17115-3

Galea, S., & Vlahov, D. (2002). Social determinants and the health of drug users: socioeconomic status, homelessness, and incarceration. Public health reports (Washington, D.C. : 1974), 117 Suppl 1(Suppl 1), S135–S145.

Guerra Velázquez, G. R. (2022). Hurricane María and Public Health in Puerto Rico: Lessons

Learned to Increase Resiliency and Prepare for Future Disasters. Annals of global health, 88(1), 82. https://doi.org/10.5334/aogh.3869

Healthy People 2030. (n.d.). Social determinants of health. U.S. Department of Health and Human Services, Office of Disease Prevention and Health Promotion. https://health.gov/healthypeople/priority-areas/social-determinants-health

Hillberry, R. H., Cases J., Manuel F. (2024) Economic Consequences of Cabotage Restrictions : The Effect of the Jones Act on Puerto Rico (English). Policy Research working paper ; no. WPS 10780; PROSPERITY Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/099257005212415735

Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1–55. https://doi.org/10.1080/10705519909540118

Kuh, D., Ben-Shlomo, Y., Lynch, J., Hallqvist, J., & Power, C. (2003). Life course epidemiology. *Journal of epidemiology and community health*, *57*(10), 778–783. https://doi.org/10.1136/jech.57.10.778

Lafarga Previdi, I., & Vélez Vega, C. M. (2020). Health Disparities Research Framework Adaptation to Reflect Puerto Rico's Socio-Cultural Context. *International journal of environmental research and public health*, *17*(22), 8544. https://doi.org/10.3390/ijerph17228544

Lanza, S. T., & Rhoades, B. L. (2013). Latent class analysis: an alternative perspective on subgroup analysis in prevention and treatment. *Prevention science*, *14*(2), 157-168. https://doi.org/10.1007/s11121-011-0201-1

Lin, C., Cousins, S. J., Zhu, Y., Clingan, S. E., Mooney, L. J., Kan, E., Wu, F., & Hser, Y. I.

(2024). A scoping review of social determinants of health's impact on substance use disorders over the life course. Journal of substance use and addiction treatment, 166, 209484. https://doi.org/10.1016/j.josat.2024.209484

McCarthy, M. L., Zheng, Z., Wilder, M. E., Elmi, A., Kulie, P., Johnson, S., & Zeger, S. L. (2021). Latent class analysis to represent social determinant of health risk groups in the medicaid cohort of the District of Columbia. *Medical Care*, *59*(3), 251–258. https://doi.org/10.1097/MLR.0000000000001468

Mattei, J., Tucker, K. L., Falcón, L. M., Ríos-Bedoya, C. F., Kaplan, R. M., O'Neill, H. J., Tamez, M., Mendoza, S., Díaz-Álvarez, C. B., Orozco, J. E., Acosta Pérez, E., & Rodríguez-Orengo, J. F. (2021). Design and Implementation of the Puerto Rico Observational Study of Psychosocial, Environmental, and Chronic Disease Trends (PROSPECT). American journal of epidemiology, 190(5), 707–717. https://doi.org/10.1093/aje/kwaa231

Martin, J. N., & Pace, T. W. W. (2025). Colonialism as a Social Determinant of Health in Puerto Rico: Using the Socioecological Model to Examine How the Jones Act Impacted Health After Hurricane María. Journal of transcultural nursing : official journal of the Transcultural Nursing Society, 36(1), 8–15. https://doi.org/10.1177/10436596241274123

McCarthy, M. L., Zheng, Z., Wilder, M. E., Elmi, A., Kulie, P., Johnson, S., & Zeger, S. L. (2021). Latent Class Analysis to Represent Social Determinant of Health Risk Groups in the Medicaid Cohort of the District of Columbia. Medical care, 59(3), 251–258. https://doi.org/10.1097/MLR.0000000000001468

McSorley, A. M., Rivera-González, A. C., Mercado, D. L., Pagán, J. A., Purtle, J., & Ortega, A.

N. (2024). United States Federal Policies Contributing to Health and Health Care Inequities in Puerto Rico. American journal of public health, 114(S6), S478–S484. https://doi.org/10.2105/AJPH.2024.307585

Na, P. J., Shin, J., Kwak, H. R., Lee, J., Jester, D. J., Bandara, P., Kim, J. Y., Moutier, C. Y., Pietrzak, R. H., Oquendo, M. A., & Jeste, D. V. (2025). Social Determinants of Health and Suicide-Related Outcomes: A Review of Meta-Analyses. JAMA psychiatry, 82(4), 337–346. https://doi.org/10.1001/jamapsychiatry.2024.4241

National Institute on Minority Health and Health Disparities (2025). NIMHD Research Framework. Retrieved from https://nimhd.nih.gov/researchFramework

Patil, I. (2021). Visualizations with statistical details: The 'ggstatsplot' approach. Journal of Open Source Software, *6*(61), 3167. https://doi.org/10.21105/joss.03167

Peña-Vargas, C., Toro-Morales, Y., Valentin, P., López, M., Rodriguez-Castro, Z., Hernandez-Torres, R., Tollinchi-Natali, N., Torres-Blasco, N., Pereira, C., Armaiz-Pena, G. N., Jim, H., & Castro-Figueroa, E. M. (2022). Impact of Seismic Activity on Access to Health Care in Hispanic/Latino Cancer Patients from Puerto Rico. *International Journal of Environmental Research and Public Health*, 19(7), 4246. https://doi.org/10.3390/ijerph19074246

Political Status of Puerto Rico: Brief Background and Recent Developments for Congress. (2025). https://www.congress.gov/crs-product/R44721

R Core Team. (2025). R: A language and environment for statistical computing (Version 4.5.0) [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/

Revelle, W. (2024). psych: Procedures for personality and psychological research (Version

2.4.1). Northwestern University. https://CRAN.R-project.org/package=psych

RStudio Team. (2024). RStudio: Integrated development environment for R (Version 2024.12.1+563) [Computer software]. Posit PBC. https://posit.co/products/open-source/rstudio/

Saunders, R., Buckman, J. E. J., & Pilling, S. (2020). Latent variable mixture modelling and individual treatment prediction. *Behaviour research and therapy*, *124*, 103505. https://doi.org/10.1016/j.brat.2019.103505

Schiltz, N. K., Chagin, K., & Sehgal, A. R. (2022). Clustering of social determinants of health among patients. *Journal of primary care & community health*, *13*, 21501319221113543. https://doi.org/10.1177/21501319221113543

Shokoohi, M., Bauer, G. R., Kaida, A., Logie, C. H., Lacombe-Duncan, A., Milloy, M. J., Lloyd-Smith, E., Carter, A., Loutfy, M., & CHIWOS Research Team (2019). Patterns of social determinants of health associated with drug use among women living with HIV in Canada: A latent class analysis. *Addiction*, *114*(7), 1214–1224. https://doi.org/10.1111/add.14566

Suzuki, S., Longcoy, J., Isgor, Z., Avery, E., Johnson, T. J., Yang, E., & Lynch, E. B. (2024). Clustering of social determinants of health as an indicator of meaningful subgroups within an African American population: Application of latent class analysis. *International Journal of Environmental Research and Public Health*, *21*(6), 676. https://doi.org/10.3390/ijerph21060676

Trujillo, M. A., Perrin, P. B., Sutter, M., Tabaac, A., & Benotsch, E. G. (2017). The buffering

role of social support on the associations among discrimination, mental health, and suicidality in a transgender sample. *The International Journal of Transgenderism*, *18*(1), 39–52. https://doi.org/10.1080/15532739.2016.1247405

United States Census Bureau QuickFacts. (n.d.). U.S. Census Bureau QuickFacts: Puerto Rico. Census Bureau QuickFacts. https://www.census.gov/quickfacts/fact/table/PR/PST045224

van Buuren, S., & Groothuis-Oudshoorn, K. (2011). mice: Multivariate imputation by chained equations in R. Journal of Statistical Software, 45(3), 1–67. https://doi.org/10.18637/jss.v045.i03

Varas-Díaz, N., Rodríguez-Madera, S., Padilla, M., Rivera-Bustelo, K., Mercado-Ríos, C., Rivera-Custodio, J., Matiz-Reyes, A., Santiago-Santiago, A., González-Font, Y., Vertovec, J., Ramos-Pibernus, A., & Grove, K. (2023). On leaving: Coloniality and physician migration in Puerto Rico. Social science & medicine (1982), 325, 115888. https://doi.org/10.1016/j.socscimed.2023.115888

Vu, M., Li, J., Haardörfer, R. et al. Mental health and substance use among women and men at the intersections of identities and experiences of discrimination: insights from the intersectionality framework. BMC Public Health 19, 108 (2019). https://doi.org/10.1186/s12889-019-6430-0

Weller, B. E., Bowen, N. K., & Faubert, S. J. (2020). Latent class analysis: a guide to best practice. *Journal of black psychology*, *46*(4), 287-311. https://doi.org/10.1177/0095798420930932

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., ... & Yutani, H. (2019). Welcome to the tidyverse. Journal of Open Source Software, 4(43), 1686. https://doi.org/10.21105/joss.01686

World Health Organization. (n.d.). Social determinants of health. https://www.who.int/health-topics/social-determinants-of-health

Yelton, B., Friedman, D. B., Noblet, S., Lohman, M. C., Arent, M. A., Macauda, M. M., Sakhuja, M., & Leith, K. H. (2022). Social Determinants of Health and Depression among African American Adults: A Scoping Review of Current Research. International journal of environmental research and public health, 19(3), 1498. https://doi.org/10.3390/ijerph19031498

## Appendix

## Tables and Figures

**Table 3.1** Fit Statistics for Latent Class Analyses

| Model | Log likelihood | DF | Relative entropy | AIC | BIC | $X^2$ log likelihood difference | *p* | Class size (*n*) |
|---|---|---|---|---|---|---|---|---|
| One-class | -20136.10 | 1013 | - | 40292.20 | 20356.53 | - | - | 4594 |
| Two-class | -18766.82 | 1002 | .702 | 37575.63 | 37710.71 | 2738.571 | < .001 | 1265 \| 3329 |
| Three-class | -18525.69 | 991 | .749 | 37115.39 | 37321.23 | 482.246 | < .001 | 560 \| 673 \| 3361 |
| Four-class | -18391.55 | 980 | .714 | 36869.10 | 37145.69 | 268.291 | < .001 | 239 \| 701 \| 798 \| 2856 |
| Five-class | -18361.75 | 969 | .720 | 36831.50 | 37178.86 | 59.596 | .005 | 251 \| 262 \| 499 \| 618 \| 2964 |
| Six-class | -18340.47 | 958 | .686 | 37229.05 | 37229.05 | 42.563 | .248 | 131 \| 258 \| 264 \| 418 \| 797 \| 2726 |

*Note:* DF = Degrees of freedom, AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion, BLRT = Bootstrapped Likelihood Ratio Test.

**Table 3.2** Sample Demographics by SDOH Latent Class Membership with Missing Data Imputation

| | Total | Material scarcity | Unmeet support and stress | Low needs | General unmet needs | *p* |
|---|---|---|---|---|---|---|
| | (*n* = 4594) | (*n* = 798) | (*n* = 701) | (*n* = 2856) | (*n* = 239) | |
| Age | | | | | | < .001 |
| 18-24 | 280 (6.1%) | 38 (4.8%) | 57 (8.1%) | 171 (6%) | 14 (5.9%) | |
| 25-34 | 638 (13.9%) | 119 (14.9%) | 108 (15.4%) | 361 (12.6%) | 50 (20.9%) | |
| 35-44 | 676 (14.7%) | 148 (18.5%) | 90 (12.8%) | 394 (13.8%) | 44 (18.4%) | |
| 45-54 | 844 (18.4%) | 174 (21.8%) | 130 (18.5%) | 488 (17.1%) | 52 (21.8%) | |
| 55-64 | 919 (20%) | 169 (21.2%) | 144 (20.5%) | 545 (19.1%) | 61 (25.5%) | |
| 65+ | 1237 (26.9%) | 150 (18.8%) | 172 (24.5%) | 897 (31.4%) | 18 (7.5%) | |
| Sex | | | | | | < .001 |
| Male | 1722 (37.5%) | 240 (30.1%) | 229 (32.7%) | 1193 (41.8%) | 60 (25.1%) | |
| Female | 2872 (62.5%) | 558 (69.9%) | 472 (67.3%) | 1663 (58.2%) | 179 (74.9%) | |
| Race/ethnicity | | | | | | |
| Hispanic | 4553 (99.1%) | 792 (99.2%) | 694 (99%) | 2830 (99.1%) | 237 (99.2%) | |
| White | 28 (0.6%) | 4 (0.5%) | 4 (0.6%) | 18 (0.6%) | 2 (0.8%) | |
| Black | 10 (0.2%) | 2 (0.3%) | 2 (0.3%) | 6 (0.2%) | 0 (0%) | |
| Multiple groups | 1 (0%) | 0 (0%) | 1 (0.1%) | 0 (0%) | 0 (0%) | |
| Other | 2 (0%) | 0 (0%) | 0 (0%) | 2 (0.1%) | 0 (0%) | |
| Income | | | | | | < .001 |
| < 15,000 | 1321 (28.8%) | 360 (45.1%) | 248 (35.4%) | 603 (21.1%) | 110 (46%) | |
| 15,000-<25,000 | 1118 (24.3%) | 207 (25.9%) | 180 (25.7%) | 669 (23.4%) | 62 (25.9%) | |
| 25,000-<35,000 | 747 (16.3%) | 117 (14.7%) | 104 (14.8%) | 489 (17.1%) | 37 (15.5%) | |
| 35,000-<50,000 | 672 (14.6%) | 74 (9.3%) | 79 (11.3%) | 500 (17.5%) | 19 (7.9%) | |
| 50,000-<100,000 | 541 (11.8%) | 33 (4.1%) | 75 (10.7%) | 424 (14.8%) | 9 (3.8%) | |
| 100,000-<200,000 | 147 (3.2%) | 5 (0.6%) | 11 (1.6%) | 130 (4.6%) | 1 (0.4%) | |
| 200,000+ | 48 (1%) | 2 (0.3%) | 4 (0.6%) | 41 (1.4%) | 1 (0.4%) | |
| Education | | | | | | < .001 |
| < High school | 516 (11.2%) | 105 (13.2%) | 89 (12.7%) | 296 (10.4%) | 26 (10.9%) | |
| High school | 1135 (24.7%) | 217 (27.2%) | 189 (27%) | 666 (23.3%) | 63 (26.4%) | |
| Some college/tech | 1231 (26.8%) | 244 (30.6%) | 173 (24.7%) | 727 (25.5%) | 87 (36.4%) | |
| College/tech | 1712 (37.3%) | 232 (29.1%) | 250 (35.7%) | 1167 (40.9%) | 63 (26.4%) | |

Note: SDOH = Social determinants of health, *p* = *p*-value for chi-square test of independence.

**Table 3.3** SDOH Latent Classes by Health Outcomes with Missing Data Imputation

| | Total | Material scarcity | Unmeet support and stress | Low needs | General unmet needs | *p* |
|---|---|---|---|---|---|---|
| | (*n* = 4594) | (*n* = 798) | (*n* = 701) | (*n* = 2856) | (*n* = 239) | |
| **SDOH** | | | | | | |
| Life dissatisfaction | 203 (4.4%) | 7 (0.9%) | 134 (19.1%) | 11 (0.4%) | 51 (21.3%) | < .001 |
| Emotional support | 779 (17%) | 73 (9.1%) | 412 (58.8%) | 149 (5.2%) | 145 (60.7%) | < .001 |
| Loneliness | 1625 (35.4%) | 212 (26.6%) | 671 (95.7%) | 517 (18.1%) | 225 (94.1%) | < .001 |
| Employment loses | 479 (10.4%) | 135 (16.9%) | 78 (11.1%) | 181 (6.3%) | 85 (35.6%) | < .001 |
| Food stamps | 2040 (44.4%) | 579 (72.6%) | 347 (49.5%) | 963 (33.7%) | 151 (63.2%) | < .001 |
| Food insecurity | 1021 (22.2%) | 515 (64.5%) | 185 (26.4%) | 134 (4.7%) | 187 (78.2%) | < .001 |
| Paying bills | 684 (14.9%) | 438 (54.9%) | 38 (5.4%) | 0 (0%) | 208 (87%) | < .001 |
| Threatened loss of utilities | 365 (7.9%) | 235 (29.4%) | 0 (0%) | 0 (0%) | 130 (54.4%) | < .001 |
| Transportation | 485 (10.6%) | 149 (18.7%) | 149 (21.3%) | 71 (2.5%) | 116 (48.5%) | < .001 |
| Stress | 954 (20.8%) | 117 (14.7%) | 417 (59.5%) | 208 (7.3%) | 212 (88.7%) | < .001 |
| Cumulative SDOH | 1.88 (1.80) | 3.08 (1.12) | 3.47 (1.13) | 0.78 (0.74) | 6.32 (1.18) | < .001 |
| **Chronic disorders** | | | | | | |
| Heart attack | 223 (4.9%) | 40 (5%) | 48 (6.8%) | 118 (4.1%) | 17 (7.1%) | .008 |
| Angina or coronary heart disease | 257 (5.6%) | 41 (5.1%) | 62 (8.8%) | 131 (4.6%) | 23 (9.6%) | <. 001 |
| Stroke | 118 (2.6%) | 21 (2.6%) | 27 (3.9%) | 56 (2%) | 14 (5.9%) | < .001 |
| Asthma | 969 (21.1%) | 202 (25.3%) | 205 (29.2%) | 469 (16.4%) | 93 (38.9%) | < .001 |
| Skin cancer | 50 (1.1%) | 11 (1.4%) | 7 (1%) | 31 (1.1%) | 1 (0.4%) | |
| Melanoma | 342 (7.4%) | 51 (6.4%) | 50 (7.1%) | 216 (7.6%) | 25 (10.5%) | |
| COPD, emphysema, or chronic bronchitis | 278 (6.1%) | 57 (7.1%) | 61 (8.7%) | 127 (4.4%) | 33 (13.8%) | < .001 |
| Depression | 797 (17.3%) | 134 (16.8%) | 286 (40.8%) | 253 (8.9%) | 124 (51.9%) | < .001 |
| Kidney disease | 202 (4.4%) | 54 (6.8%) | 38 (5.4%) | 93 (3.3%) | 17 (7.1%) | < .001 |
| Arthritis, rheumatoid arthritis, gout, lupus, or fibromyalgia | 1296 (28.2%) | 248 (31.1%) | 260 (37.1%) | 705 (24.7%) | 83 (34.7%) | < .001 |
| Diabetes | 865 (18.8%) | 163 (20.4%) | 161 (23%) | 489 (17.1%) | 52 (21.8%) | .001 |
| Cumulative chronic disorders | 1.17 (1.35) | 1.28 (1.45) | 1.72 (1.59) | 0.94 (1.16) | 2.02 (1.60) | < .001 |

*Note:* SDOH = Social determinants of health, *p* = *p*-value for chi-square test of independence or Kruskal-Wallis test.

**Table 3.3** SDOH Latent Classes by Health Outcomes with Missing Data Imputation (Continued)

| | Total | Material scarcity | Unmeet support and stress | Low needs | General unmet needs | *p* |
|---|---|---|---|---|---|---|
| | (*n* = 4594) | (*n* = 798) | (*n* = 701) | (*n* = 2856) | (*n* = 239) | |
| **Wellbeing and behavioral health** | | | | | | |
| Perceived physical health status | 5.78 (9.98) | 6.76 (10.64) | 9.27 (11.74) | 4.20 (8.59) | 11.23 (12.35) | < .001 |
| Perceived mental health status | 4.06 (8.82) | 4.14 (8.95) | 10.07 (11.98) | 1.77 (5.68) | 13.48 (12.90) | < .001 |
| Alcohol use | 1491 (32.5%) | 227 (28.4%) | 227 (32.4%) | 968 (33.9%) | 69 (28.9%) | .019 |
| Tobacco use | 342 (7.4%) | 70 (8.8%) | 65 (9.3%) | 172 (6%) | 35 (14.6%) | < .001 |
| Electronic cigarette use | 79 (1.7%) | 13 (1.6%) | 17 (2.4%) | 39 (1.4%) | 10 (4.2%) | .005 |

*Note:* SDOH = Social determinants of health, *p* = *p*-value for chi-square test of independence or Kruskal-Wallis test.

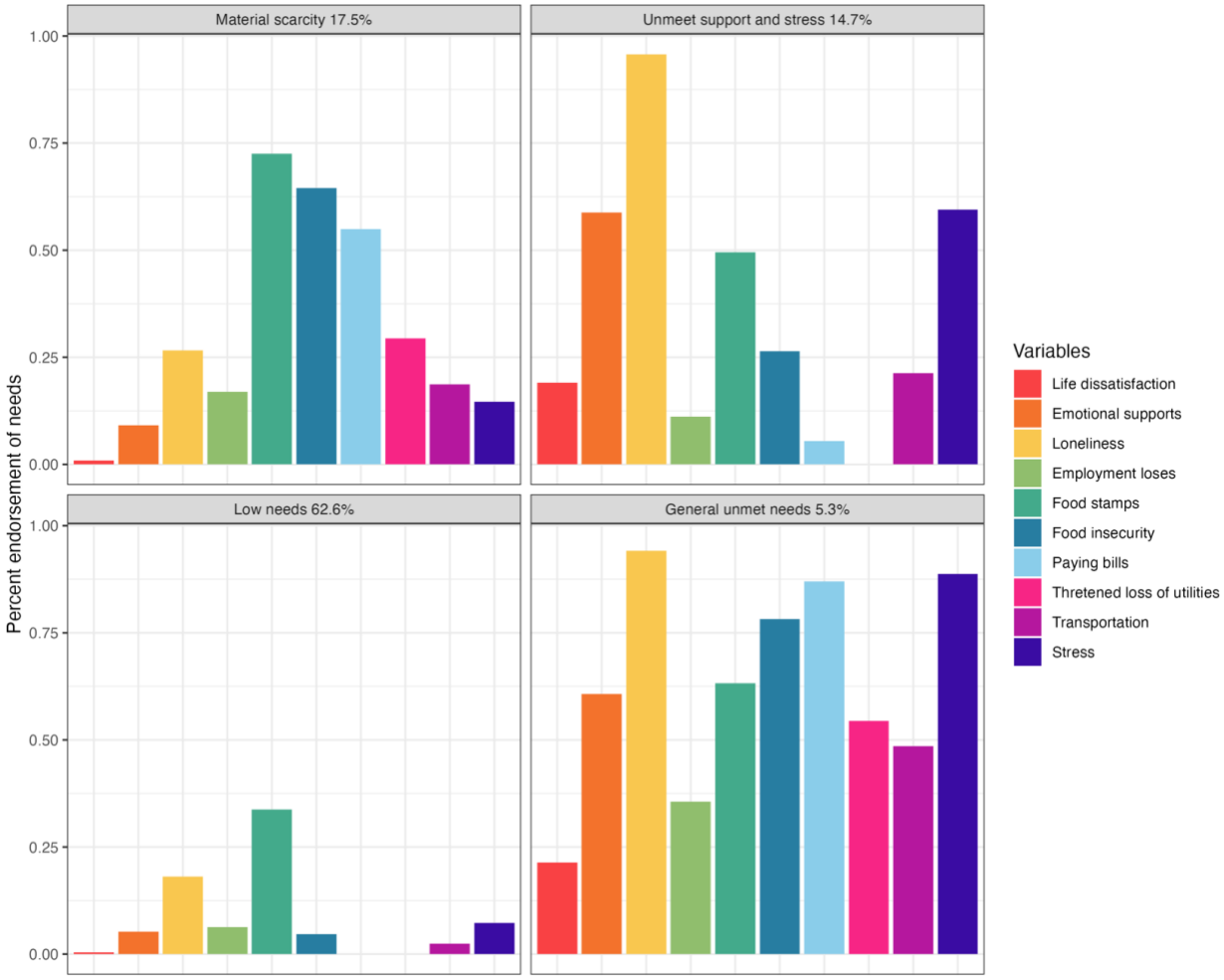



**Figure 3.1** SDOH Four-Class Solution

*Note:* SDOH = Social determinants of health

## Supplemental

## Tables and Figures

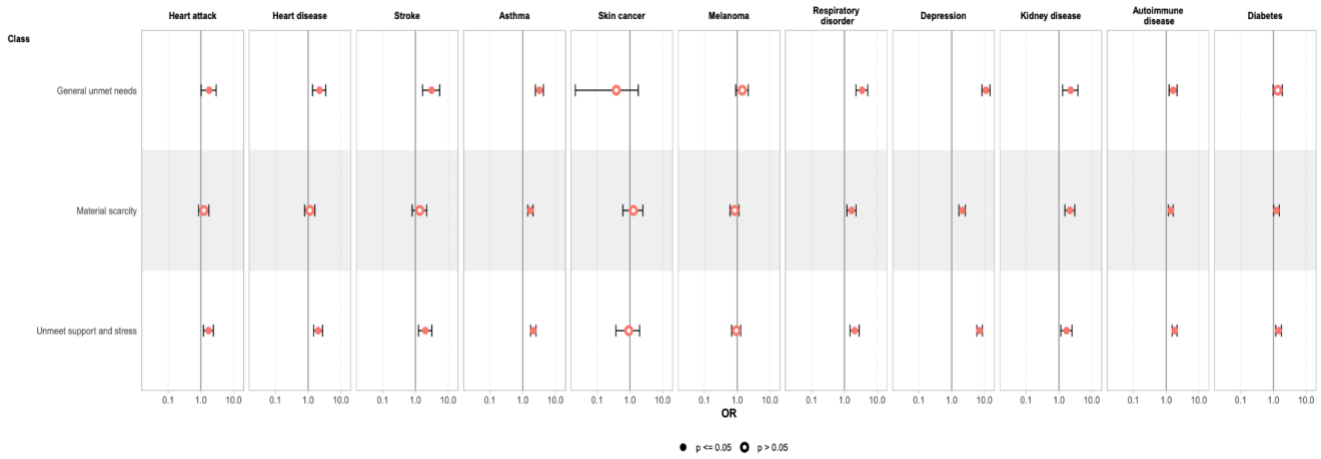
**Supplemental Table 3.1** Unimputed Sample Demographics

| Demographics | Mean/Count (SD/%) ($n$ = 4594) |
|---|---|
| Age | |
| 18-24 | 280 (6.1%) |
| 25-34 | 638 (13.9%) |
| 35-44 | 676 (14.7%) |
| 45-54 | 844 (18.4%) |
| 55-64 | 919 (20%) |
| 65+ | 1237 (26.9%) |
| Sex | |
| Male | 1722 (37.5%) |
| Female | 2872 (62.5%) |
| Race/ethnicity | |
| Hispanic | 4544 (98.9%) |
| White | 28 (0.6%) |
| Black | 10 (0.2%) |
| Multiple | 1 (0%) |
| Other | 2 (0%) |
| Education | |
| Less than high school | 513 (11.2%) |
| High school | 1132 (24.6%) |
| Some college/tech | 1229 (26.8%) |
| College/tech | 1708 (37.2%) |
| Income | |
| < 15,000 | 1026 (22.3%) |
| 15,000-<25,000 | 908 (19.8%) |
| 25,000-<35,000 | 606 (13.2%) |
| 35,000-<50,000 | 545 (11.9%) |
| 50,000-<100,000 | 440 (9.6%) |
| 100,000-<200,000 | 123 (2.7%) |
| 200,000+ | 37 (0.8%) |

**Supplemental Table 3.2** SDOH, Chronic Disorders, and Indicators of Wellbeing and Behavioral Health

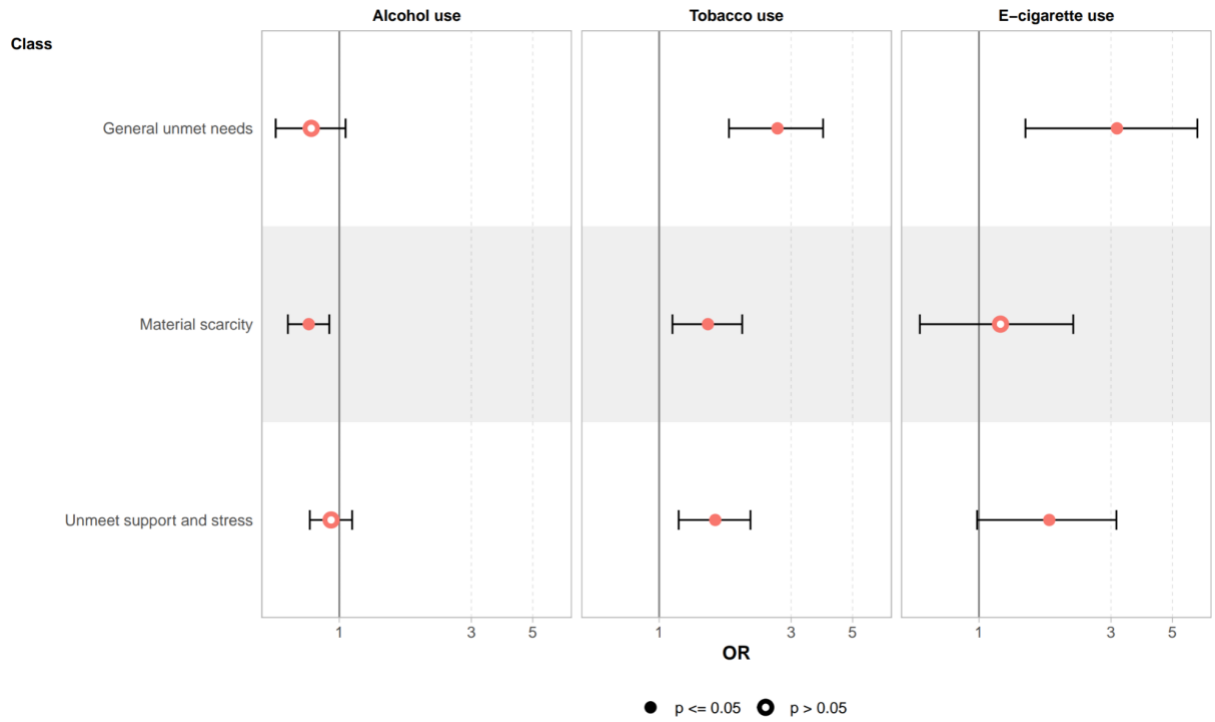
| Variables | Mean/Count (SD/%) ($n$ = 4594) |
|---|---|
| **SDOH** | |
| Life dissatisfaction | 199 (4.3%) |
| Emotional support | 763 (16.6%) |
| Loneliness | 1588 (34.6%) |
| Employment loses | 462 (10.1%) |
| Food stamps | 1992 (43.4%) |
| Food insecurity | 999 (21.7%) |
| Paying bills | 674 (14.7%) |
| Threatened loss of utilities | 363 (7.9%) |
| Transportation | 483 (10.5%) |
| Stress | 927 (20.2%) |
| Cumulative SDOH | 1.86 (1.80) |
| **Chronic disorders** | |
| Heart attack | 223 (4.9%) |
| Angina or coronary heart disease | 255 (5.6%) |
| Stroke | 118 (2.6%) |
| Asthma | 967 (21%) |
| Skin cancer | 50 (1.1%) |
| Melanoma | 342 (7.4%) |
| COPD, emphysema, or chronic bronchitis | 278 (6.1%) |
| Depression | 795 (17.3%) |
| Kidney disease | 201 (4.4%) |
| Arthritis, rheumatoid arthritis, gout, lupus, or fibromyalgia | 1284 (27.9%) |
| Diabetes | 863 (18.8%) |
| Cumulative chronic disorders | 1.16 (1.34) |
| **Wellbeing and behavioral health** | |
| Perceived physical health status | 5.78 (9.97) |
| Perceived mental health status | 4.06 (8.84) |
| Alcohol use | 1456 (31.7%) |
| Tobacco use | 341 (7.4%) |
| Electronic cigarette use | 78 (1.7%) |

*Notes:* SDOH = Social determinants of health.




**Supplemental Figure 3.1** Logistic Regression Analyses: SDOH Class Membership Associations with Individual Health Outcomes

*Note:* Reference group = Low Need Class.




**Supplemental Figure 3.2** Logistic Regression Analyses: SDOH Class Membership Associations with Behavioral Health Outcomes

*Note:* Reference group = Low Need Class.

# Chapter V

## Conclusion

SDOH function through complex interactions, promoting wellness in some populations while worsening inequities in others. Substantial research demonstrates that SDOH are among the most significant predictors of health outcomes and this dynamic is particularly evident in Puerto Rico, where deep-seated health disparities are heightened by economic instability, a strained healthcare infrastructure, and insufficient social protections (Braveman & Gottlieb, 2014; Chelak & Chakole, 2023; McSorley et al., 2024). Researchers link these disparities to the island's colonial legacy, which may serve as a fundamental SDOH by dictating the structural conditions, opportunities, and resource access available to its residents. (Martin & Pace, 2025; McSorley et al., 2024). Despite the significance of these factors, population-level data for Puerto Rico remains limited, and multi-determinant analyses are rare. This dissertation sought to address these gaps by examining the distribution, cumulative impact, and health consequences of SDOH among adults residing in Puerto Rico, using various statistical approaches. The findings provide insight into the prevalence of SDOH, their relationships with self-rated and chronic health outcomes, and the potential protective roles of resilience and community support.

The first manuscript (Chapter II) focused on SRH outcomes and the association with multiple SDOH indicators using data from the 2023 BRFSS for adults residing in Puerto Rico. Descriptive analyses indicated that participants were predominantly female and older, with a majority reporting household incomes below the 2023 Puerto Rican median of $25,000 and some college or higher education. Marital status was distributed across married, divorced, widowed, separated, never married, and unmarried couples. Unadjusted and adjusted analyses demonstrated significant associations between multiple SDOH indicators—including life

dissatisfaction, limited emotional support, loneliness, food insecurity, transportation barriers, and stress—and poorer self-rated general, physical, and mental health outcomes. Older age and lower income were consistently associated with worse health, whereas higher educational attainment was protective.

Analyses of physically unhealthy days revealed that life dissatisfaction, stress, and transportation barriers were associated with more days of poor physical health. Mentally unhealthy days were strongly predicted by life dissatisfaction and stress, with additional contributions from income, educational attainment, and marital status. These results highlight that individual SDOH operate both independently and cumulatively to influence health, emphasizing the importance of addressing multiple dimensions of social disadvantage when designing public health interventions.

The second manuscript (Chapter III) extended the examination of SDOH by assessing their collective influence on chronic and behavioral health outcomes among adults in Puerto Rico, using 2023 BRFSS data. Descriptive analyses indicated high prevalence of food-related hardship and social isolation. Common chronic conditions included arthritis, asthma, and diabetes, while kidney disease, stroke, and skin cancer were less prevalent. Behavioral risk factors included alcohol use, current cigarette use, and e-cigarette use.

Tetrachoric correlations demonstrated interrelations among financial hardship indicators and emotional or social measures, reflecting the clustering of adverse SDOH. Elastic Net logistic regression models indicated that employment loss, food insecurity, stress, and transportation barriers were among the most influential predictors across health outcomes, although the specific pattern of predictive importance varied by condition. For example, cardiovascular outcomes were primarily classified by employment loss and food stamp usage, respiratory outcomes by

stress and loneliness, and depression by stress and social isolation. Behavioral outcomes such as cigarette smoking were influenced by employment instability, food insecurity, and stress, while alcohol use was predominantly predicted by food stamp usage. These findings emphasize that multiple SDOH collectively shape health outcomes and that the relative contribution of specific determinants differs across chronic and behavioral health domains. The results provide a foundation for risk stratification and targeted intervention planning at the population level, highlighting areas for public health resource allocation.

In the third manuscript (Chapter IV), a latent class analysis was utilized to identify patterns of cumulative SDOH and explore their relationships with chronic and behavioral health outcomes among adults in Puerto Rico. Four distinct SDOH subgroups were identified: Low Needs (n = 2,856), Material Scarcity (n = 798), Unmet Support and Stress (n = 701), and General Unmet Needs (n = 239). Individuals in the General High Needs subgroup experienced the highest cumulative burden across SDOH and reported the poorest physical, mental, and behavioral health outcomes, while those in the Low Needs subgroup faced relatively minimal social risks and better health outcomes.

These findings highlight the additive effects of multiple SDOH. Subgroups characterized by overlapping economic and psychosocial vulnerabilities experienced significantly worse outcomes, emphasizing the importance of examining SDOH holistically rather than individually. The variation across subgroups also suggests that targeted interventions addressing specific combinations of social risk—such as material hardship or psychosocial stress—may be more effective than one-size-fits-all approaches. Identifying population subgroups with distinct SDOH profiles offers actionable insights for public health practitioners and policymakers, supporting

the design of tailored strategies to mitigate social inequities, reduce chronic disease burden, and improve overall population health.

This dissertation documents the prevalence, patterns, and impacts of SDOH on physical, mental, and behavioral health outcomes among adults residing in Puerto Rico. By analyzing multiple dimensions of social vulnerability, it provides a detailed portrait of how non-medical factors shape health disparities in this population. The work not only identifies which SDOH are most strongly associated with poor health outcomes but also examines how these determinants interact cumulatively to create distinct risk profiles across the population.

In addition, the dissertation demonstrates the utility of both traditional and advanced analytic approaches. Manuscript 1 highlights descriptive patterns of SDOH and their associations with self-rated physical and mental health. Manuscript 2 features a particularly notable aspect of this dissertation with the use of Elastic net logistic regression given that SDOH are often highly correlated which can create challenges for traditional regression approaches (Zou & Hastie, 2005; Vatcheva et al., 2016). Elastic net addresses this issue by allowing for robust variable selection while accounting for multicollinearity (Tay et al., 2023). This approach enabled the identification of the most influential SDOH across a range of chronic and behavioral health outcomes, providing a nuanced understanding of which social vulnerabilities matter most for specific conditions. Manuscript 3 expands this work by using latent class analysis to identify subgroups with distinct SDOH profiles, demonstrating how cumulative disadvantage corresponds to the greatest health burdens.

Collectively, this dissertation provides a detailed portrait of SDOH in Puerto Rico, documenting both individual and cumulative social risks and their associations with health outcomes. By utilizing descriptive, regression, and latent class methodologies, the research

demonstrates the importance of examining SDOH holistically and highlights how specific determinants cluster to create distinct risk profiles. Importantly, the use of Elastic Net regression illustrates a practical solution for analyzing highly correlated SDOH data, a common challenge in public health research, while latent class analysis reveals subpopulations most affected by social disadvantage. These methodological approaches provide a roadmap for future research in contexts with complex and interrelated social determinants.

While these findings significantly advance understanding of SDOH in Puerto Rico, several limitations should be acknowledged. Data were derived from self-reported survey responses, which may be subject to recall bias or social desirability effects. Despite this, self-reported health indicators (e.g., BRFSS) are staples of population-based surveillance and have proven valid for epidemiological research. The cross-sectional design does not allow for causal inference, and certain subpopulations—such as rural residents or individuals not captured by telephone-based surveys—may be underrepresented. These results indicate an association but do not confirm causation; subsequent longitudinal studies should investigate these temporal relationships, including the currently underrepresented role of those in the present sample. Additionally, some SDOH were measured with single indicators, which may not fully capture the complexity of social disadvantage. Despite these limitations, the analyses provide valuable insights into patterns of social determinants and their cumulative effects on health in a population where research is scarce.

## Future Directions

The implications of this work extend to public health practice and policy. Identifying the SDOH most strongly associated with poor health outcomes provides actionable targets for intervention, resource allocation, and policy development. For instance, addressing food

insecurity, employment instability, and transportation barriers could substantially improve physical, mental, and behavioral health outcomes in Puerto Rico. Subgroup-based findings suggest that interventions tailored to populations experiencing multiple overlapping vulnerabilities may be more effective than one-size-fits-all strategies. Furthermore, these findings reinforce the need to strengthen community and social support networks, which may buffer the adverse effects of social disadvantage and promote health equity.

Beyond the empirical findings, this dissertation raises important conceptual considerations regarding how SDOH are understood and measured in population health research. Much of the existing literature conceptualizes SDOH as upstream determinants that operate through relatively linear pathways to influence downstream health outcomes. However, the findings from this work suggest that such models may oversimplify the complexity of social vulnerability in settings such as Puerto Rico. The modest classification performance observed in the elastic net models indicates that commonly used surveillance-based indicators may only partially capture the structural forces shaping health outcomes. Dichotomous indicators such as food insecurity, employment loss, or transportation barriers provide limited information regarding the intensity, duration, and cumulative burden of hardship experienced by individuals and communities. As a result, these measures may underestimate the true magnitude and complexity of social adversity and its relationship with disease risk (Altman & Royston, 2006; McGuire et al., 2024). This limitation is particularly important when studying populations exposed to overlapping structural and economic vulnerabilities.

These findings align with broader calls within social epidemiology to reconsider how SDOH are operationalized and measured in population health research. Rather than treating social risks as isolated variables, future research should prioritize multidimensional and life-

course approaches that capture the accumulation, persistence, and interaction of social exposures (Berkman & Kawachi, 2014). Continuous measures, composite indices, and repeated assessments of social conditions may provide a more accurate representation of lived experiences of hardship. Additionally, integrating contextual factors such as neighborhood conditions, environmental exposures, healthcare access, and policy environments could substantially improve the explanatory power of SDOH research (Lafarga Previdi & Vélez Vega, 2020). The latent class analysis presented in Manuscript 3 illustrates the value of person-centered approaches in capturing distinct patterns of social vulnerability that may otherwise be obscured in traditional variable-centered models.

Importantly, the Puerto Rican context highlights the necessity of situating SDOH within broader structural and political systems. Puerto Rico's colonial relationship with the United States has profoundly shaped the economic, political, and social conditions that influence population health on the island. Researchers increasingly recognize that colonial governance structures may function as fundamental determinants of health by shaping the distribution of resources, economic opportunities, and institutional power available to populations (Martin & Pace, 2025; McSorley et al., 2024). Structural policies and federal regulations have contributed to persistent economic instability, high poverty rates, and limited fiscal autonomy for the island. For example, the Jones Act maritime law increases the cost of goods and supplies imported to Puerto Rico, including essential healthcare resources, thereby contributing to broader economic strain (Hillberry et al., 2024). These structural constraints interact with additional stressors, including population outmigration, healthcare workforce shortages, and repeated natural disasters such as Hurricanes Irma and Maria and the earthquakes of 2019–2020, which have

further strained the island's economic and healthcare systems (Guerra Vélazquez, 2022; Varas-Díaz et al., 2023).

Recognizing these structural dynamics has important implications for how health disparities are conceptualized and addressed. Traditional public health approaches often emphasize modifying individual health behaviors or addressing discrete social risk factors. While such strategies are important, they may be insufficient in contexts where structural inequities are deeply embedded within political and economic systems. The findings from this dissertation suggest that addressing economic insecurity, food access, transportation barriers, and social isolation may produce meaningful improvements in population health. However, long-term progress will likely require broader structural reforms that address the systemic drivers of social vulnerability (Braveman & Gottlieb, 2014). Policies aimed at strengthening economic stability, improving healthcare infrastructure, and expanding social protections may therefore play a critical role in reducing health disparities and improving population health outcomes in Puerto Rico.

Future research should continue expanding both the methodological and conceptual frameworks used to study SDOH in Puerto Rico and other structurally marginalized contexts. Longitudinal cohort studies would be particularly valuable for disentangling the reciprocal relationships between social vulnerability and health outcomes suggested by the findings of this dissertation. Prior research indicates that social risk and health conditions may operate within dynamic feedback systems, in which economic hardship and psychosocial stress increase disease risk, while chronic illness further deepens social vulnerability (Berkman & Kawachi, 2014; Berrett-Abebe & Reed, 2024). Longitudinal designs incorporating repeated assessments of social

risk, disease progression, and functional status could provide critical insight into these complex pathways.

In addition, future studies should prioritize the development of measurement frameworks capable of capturing the intensity, chronicity, and cumulative burden of social adversity. Current population health surveillance systems often rely on simplified binary indicators that may inadequately represent lived experiences of hardship. More nuanced approaches incorporating multi-item indices, continuous scales, and contextual indicators could substantially enhance the accuracy and interpretability of SDOH research (McGuire et al., 2024). Expanding measurement strategies to include neighborhood context, environmental exposures, access to care, and culturally relevant social support systems would also contribute to a more comprehensive understanding of health vulnerability within the Puerto Rican population (Lafarga Previdi & Vélez Vega, 2020).

Finally, community-engaged and interdisciplinary research approaches will be critical for advancing health equity research in Puerto Rico. Partnerships with community organizations, policymakers, and local stakeholders can help ensure that future measurement frameworks accurately reflect lived experiences and cultural contexts. Such collaborations may also facilitate the development of interventions that address both material hardship and psychosocial stress while strengthening community resilience. By integrating methodological innovation with structural and community perspectives, future research can better capture the complex realities of social vulnerability and inform more effective strategies for improving population health and reducing health disparities in Puerto Rico.

Ultimately, this dissertation highlights the complex and interconnected ways that SDOH shape the lived health experiences of Puerto Rican adults. Across three manuscripts, the findings

demonstrate that health outcomes—including self-rated, physical, and mental health—cannot be fully understood through individual conditions alone but must be examined within broader social, economic, and structural contexts. By integrating traditional epidemiologic approaches with machine learning techniques such as elastic net, this work also demonstrates the value of analytic methods capable of handling highly correlated predictors—a common challenge in research on social determinants of health. In doing so, the dissertation contributes both substantive and methodological insights to the study of population health disparities.

At the same time, the modest predictive performance observed across models describes an important reality: many factors shaping health remain difficult to capture using available survey measures. Environmental exposures, healthcare access and quality, neighborhood conditions, cultural contexts, and cumulative life-course adversity likely play substantial roles in shaping health risk but are not fully captured in existing datasets. These findings therefore highlight both the importance of the determinants examined here and the need for more comprehensive measurement approaches in future research.

Taken together, this dissertation emphasizes the importance of continuing to investigate SDOH using interdisciplinary approaches that combine theory-driven public health frameworks with advanced analytic methods. Addressing health disparities among Puerto Rican adults—and other populations experiencing structural disadvantage—will require not only improved measurement and methodological innovation, but also policy and public health interventions that address the underlying social and structural conditions shaping health. By advancing understanding of these relationships, this work aims to contribute to the broader goal of promoting health equity and improving population health. In doing so, this dissertation

contributes to a growing body of work calling for public health research and practice that not only measures disparities but actively works to dismantle the social conditions that sustain them.

## References


Altman, D. G., & Royston, P. (2006). The cost of dichotomising continuous variables. BMJ (Clinical research ed.), 332(7549), 1080. https://doi.org/10.1136/bmj.332.7549.1080

Berkman, L. F., & Kawachi, I. (2014). Social epidemiology (2nd ed.). Oxford University Press.

Berrett-Abebe, J., & Reed, S. C. (2024). Exploring the Relationship between Food Insecurity, Chronic Health Conditions, and Serious Mental Illness in the United States: Implications for Social Work. Health & social work, 49(3), 147–156. https://doi.org/10.1093/hsw/hlae012

Braveman, P., & Gottlieb, L. (2014). The social determinants of health: it's time to consider the causes of the causes. Public health reports (Washington, D.C. : 1974), 129 Suppl 2(Suppl 2), 19–31. https://doi.org/10.1177/00333549141291S206

Chelak, K., & Chakole, S. (2023). The Role of Social Determinants of Health in Promoting Health Equality: A Narrative Review. Cureus, 15(1), e33425. https://doi.org/10.7759/cureus.33425

Guerra Velázquez, G. R. (2022). Hurricane María and Public Health in Puerto Rico: Lessons Learned to Increase Resiliency and Prepare for Future Disasters. Annals of global health, 88(1), 82. https://doi.org/10.5334/aogh.3869

Hillberry, R. H., Cases J., Manuel F. (2024) Economic Consequences of Cabotage Restrictions : The Effect of the Jones Act on Puerto Rico (English). Policy Research working paper ; no. WPS 10780; PROSPERITY Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/099257005212415735

Lafarga Previdi, I., & Vélez Vega, C. M. (2020). Health Disparities Research Framework

Adaptation to Reflect Puerto Rico's Socio-Cultural Context. International journal of environmental research and public health, 17(22), 8544. https://doi.org/10.3390/ijerph17228544

Martin, J. N., & Pace, T. W. W. (2025). Colonialism as a Social Determinant of Health in Puerto Rico: Using the Socioecological Model to Examine How the Jones Act Impacted Health After Hurricane María. Journal of transcultural nursing : official journal of the Transcultural Nursing Society, 36(1), 8–15. https://doi.org/10.1177/10436596241274123

McGuire, A., Singh, A., & Jackson, Y. (2024). Let it go, let it go: Stop measuring child maltreatment as a binary yes/no. Child abuse & neglect, 155, 106994. https://doi.org/10.1016/j.chiabu.2024.106994

McSorley, A. M., Rivera-González, A. C., Mercado, D. L., Pagán, J. A., Purtle, J., & Ortega, A. N. (2024). United States Federal Policies Contributing to Health and Health Care Inequities in Puerto Rico. American journal of public health, 114(S6), S478–S484. https://doi.org/10.2105/AJPH.2024.307585

Tay, J. K., Narasimhan, B., & Hastie, T. (2023). Elastic Net Regularization Paths for All Generalized Linear Models. Journal of statistical software, 106, 1. https://doi.org/10.18637/jss.v106.i01

Varas-Díaz, N., Rodríguez-Madera, S., Padilla, M., Rivera-Bustelo, K., Mercado-Ríos, C., Rivera-Custodio, J., Matiz-Reyes, A., Santiago-Santiago, A., González-Font, Y., Vertovec, J., Ramos-Pibernus, A., & Grove, K. (2023). On leaving: Coloniality and physician migration in Puerto Rico. Social science & medicine (1982), 325, 115888. https://doi.org/10.1016/j.socscimed.2023.115888

Vatcheva, K. P., Lee, M., McCormick, J. B., & Rahbar, M. H. (2016). Multicollinearity in

Regression Analyses Conducted in Epidemiologic Studies. Epidemiology (Sunnyvale, Calif.), 6(2), 227. https://doi.org/10.4172/2161-1165.1000227

Zou, H., & Hastie, T. (2005). Regularization and variable selection via the elastic net. Journal of the Royal Statistical Society. Series B, Statistical Methodology, 67(2), 301–320. https://doi.org/10.1111/j.1467-9868.2005.00503.x

## Vita

Rebeca Nieves Rodríguez was born in Ponce, Puerto Rico, to Daisy Rodríguez Cruz and Felix Nieves Cintrón. She was raised in Ponce and attended Colegio Sagrado Corazón de Jesús. In 2014, her family relocated to Memphis, Tennessee. She completed high school at St. Benedict at Auburndale and graduated in 2018. She attended The University of Tennessee, Knoxville, Tennessee, where she earned a Bachelor of Arts in Psychology with minors in Public Health and Business Administration in 2021. In 2022, she entered the Master of Public Health program with a concentration in Epidemiology and earned her degree in 2023. She then accepted a doctoral position in the Department of Public Health at the University of Tennessee, Knoxville. In 2026, she earned the Doctor of Philosophy in Public Health Sciences (PhD). Her professional interests include social epidemiology and community health, and she plans to pursue a career focused on advancing population health and reducing health disparities.