HSR.*health* ✚

Leveraging GeoAI to Advance Public Health

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Introduction

It is an inescapable fact that social and environmental factors have profound effects on a person's health, creating both positive and negative outcomes. (1) This is seen across time, borders, and countries. Both mental and physical health, as well as childhood development and quality of life, can largely be determined by the natural environment that surrounds you, your cultural background, your educational attainment, your income bracket, and by where you live. (2)

These myriad non-biological factors, intertwined in the fabric of our society and able to curtail years off a person's life expectancy, are referred to as "social determinants of health" or SDOH for short. Understanding SDOH, their prevalence, their interaction with each other, and their ultimate effect on health outcomes is of dire importance if we are to further the mission of advancing the health of all 5+ million Pennsylvanians.

A voluminous body of research has shown us the pervasive effects of multiple social, economic, and environmental factors in health outcomes. This research suggests that in the United States:

- Your education affects your health with less educated adults reporting worse general health, a greater number of chronic health conditions, and more functional limitations and disabilities. For example, white men who did not graduate from high school have a 57% chance of reporting "fair or poor health", compared to only 9% of white men with college degrees reporting the same. (3)

- Your neighborhood affects your health with multiple studies showing lower income neighborhoods have positive correlations with low birth weight, childhood injury and abuse, and teenage pregnancy risk. Research found that on average, 10% of variation in health outcomes was due to neighborhood determinants alone, after controlling for individual and family variability (4)

- Your income affects your health: in the United States, between 2001 and 2014, researchers found that without variation, the higher your income the greater your life expectancy, with the difference in life expectancy between the top 1% and the bottom 1% of the economic spectrum being 14.6 years. (5)

- Your race and ethnicity affect your health, with African-American mothers suffering from greater rates of preterm births (3.2% greater risk of preterm birth) than White mothers even when adjusted for income. (6)

Perhaps the most disheartening fact regarding these social factors' effect on individual health is they are often socially constructed, representing a barrier to intergenerational social economic mobility that many find it challenging to break. These socially constructed factors stem from systemic differences in the way we allocate resources in our nation, lack of inclusivity in public health leadership, our historic approach to clinical research, and our inequitable application of health policy.

The COVID-19 pandemic that has engulfed the planet highlighted these deep inequities of health access and outcomes in our nation. For example, an analysis of the pandemic death toll since March of 2020, reveals that overall, Pacific Islander, Latino, Indigenous and Black Americans all experienced a death rate due to COVID-19 double or more that of White and Asian Americans. (7) These inequalities are present even absent race and/or ethnic differentiation, with U.S. counties exhibiting a higher level of economic inequality also showing a higher level of COVID-19 related morbidity and mortality. (8). Even as vaccination rates surged across the nation, the vaccination of African-Americans for example, continued to lag behind those of White Americans with an analysis by the Kaiser Health Institute showing that across 36 states where data was available, as of July 2022, only 59% of African-Americans had received at least one COVID-19 vaccine dose, compared to 64% of White Americans and 87% of Asian-Americans. This vaccination mismatch of course, creating yet another level of inequity which will only serve to deepen the deleterious effects of this pandemic on our most vulnerable communities. (9)

The Commonwealth of Pennsylvania, although long at the forefront of medical advances and clinical research in this nation, is not immune to these pervasive social inequities that lead to differential health outcomes. These inequities are not limited to COVID-19 transmission and vaccination only, but are present in nearly every public health challenge we face as a society from COVID-19 to chronic disease prevalence and treatment to drug use and abuse and to the distribution of healthcare resources.

Some stark disparities and inequalities present in the State:

- African Americans make up 11% of Pennsylvania's population but represented roughly a third of the state's COVID-19 cases in 2020, and 30% of the total of COVID-19 deaths in instances where the race was known. (10)

- In Pennsylvania, age-adjusted drug overdose fatalities in 2020 were 42.4 per 100,000, higher than the national average of 28.3 per 100,000. (11)

- 14% of Pennsylvanians live in medically underserved areas. An estimated 22% of Pennsylvanians reside in a region that is both medically underserved and identified as having a scarcity of health professionals. Most of these individuals live in rural regions, belong to a minority group, have limited access to transportation, are undereducated, and live in poverty. (12)

- 1 in 6 (or 17%) of children under 18 are living in poverty In Pennsylvania. More than three times as many children live in poverty in Black and Hispanic communities than in White communities. (13)

- In 2019, 796 newborns died before turning one year old, translating to an infant mortality rate of 5.9 deaths per 1,000 live births (14) a rate comparable to the infant mortality rates in developing countries such as Lebanon and Saudi Arabia. (15)

- In Pennsylvania, there are 82 maternal deaths for every 100,000 live births. The death rate is 163 per 100,000 live births among Black Pennsylvanians, who are already disproportionately affected by poverty and have poorer access to quality healthcare. (16)

- Approximately 2 million or 19.7% of Pennsylvanians suffer from a mental illness, ranking the state 17th in the nation for mental health. (17)

- Multiple counties in the State have no clinics offering key specialized healthcare services. Each of Pennsylvania's 67 counties has at least 1 pharmacy care desert. Twenty-five counties have no women's health clinics. (18) Ten counties have no mental health clinics (19). This represents millions of Pennsylvanians, to whom merely reaching relevant clinical services is an onerous challenge.

What gives us despair however often also gives us hope. If adverse SDOH factors are socially constructed and imposed – they can also be deconstructed and removed. To do so, it is necessary to both identify where the problem exists and quantify the magnitude of the problem.

Our Proposed Solution: The GeoMD Platform for Health Equity

The GeoMD Platform for Health Equity represents a sophisticated geospatial platform and AI workbench that public health professionals can use to identify the impact of social and environmental determinants of health on health outcomes – as well as to highlight inequity in outcomes across populations and communities. The Platform also identifies the underlying and specific SDOH factors that contribute to that inequity enabling the development of targeted interventions – clinical and social – to address the issue and achieve true health equity.
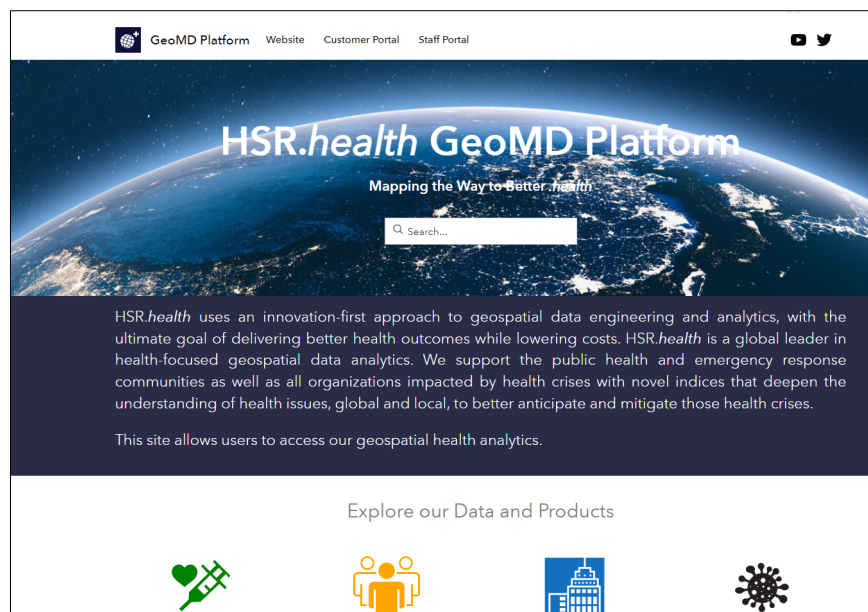
The Platform enables the objective and exhaustive study of the social and environmental factors that contribute to inequity and identifies the needs of the most vulnerable members of society – whether afflicted with chronic disease, infectious disease, natural or man-made disasters – or any combination. Leveraging the Platform, users are able to examine the relationship between numerous SDOH factors against a specific health outcome or metric of interest, such as readmissions, opioid overdose, or healthcare costs, among others, to determine not only the overall effect, but also the specific SDOH factors that impact the outcome and the degree to which they do so.

The GeoMD Platform for Health Equity allows public health professionals to look at multiple challenges currently assailing our healthcare systems at multiple levels, and to draw actionable insights to address those challenges. While the Platform is comprehensive and provides resources to address healthcare's diverse challenges, individual dashboards can be created that focus on a specific challenge or issue of interest, such as but not limited to:

- COVID-19 transmission, hospitalization, and mortality
- The combined effects of Influenza and COVID-19 on hospital systems

- Vaccination logistics, gaps, and needs
- Opioid abuse and overdose risk
- 30-Day readmission risk for hospital systems
- Total cost of care for hospital systems
- Clinical care deserts across the United States
- Zoonotic disease spillover risk globally

The GeoMD Platform provides maps at multiple geospatial levels, graphs showing trends in SDOH and outcomes over time, and charts comparing the relationship between the two. A sample interface to the GeoMD Platform is shown in Figure 1.
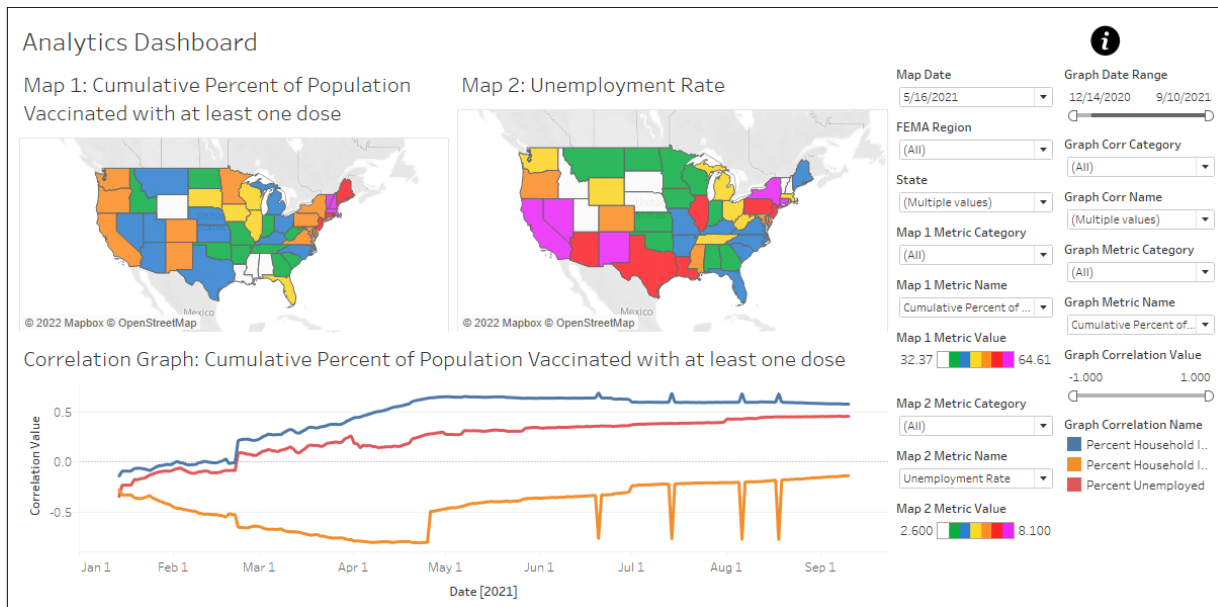

Figure 1: Sample view of the GeoMD user interface showing the relationship between unemployment and the population vaccinated with at least one COVID-19 dose.

GeoMD in Action: The Social Determinants of Health Risk Index

GeoMD, through its Social Determinants of Health (SDOH) Risk Index, one of the proprietary risk indices available through the Platform, produces a vulnerability score that identifies the overall relative risk to health outcomes based on the social factors present in a population and by region (e.g., ZIP Code or Census tract). The SDOH Risk Index is shown for the Commonwealth of Pennsylvania in Figure 2, along with a pie chart showing the distribution of Census tracks by risk level.

The SDOH Risk Index allows public health decision makers to identify where in their state or county SDOH factors are at play with deleterious effects on health outcomes to their population.
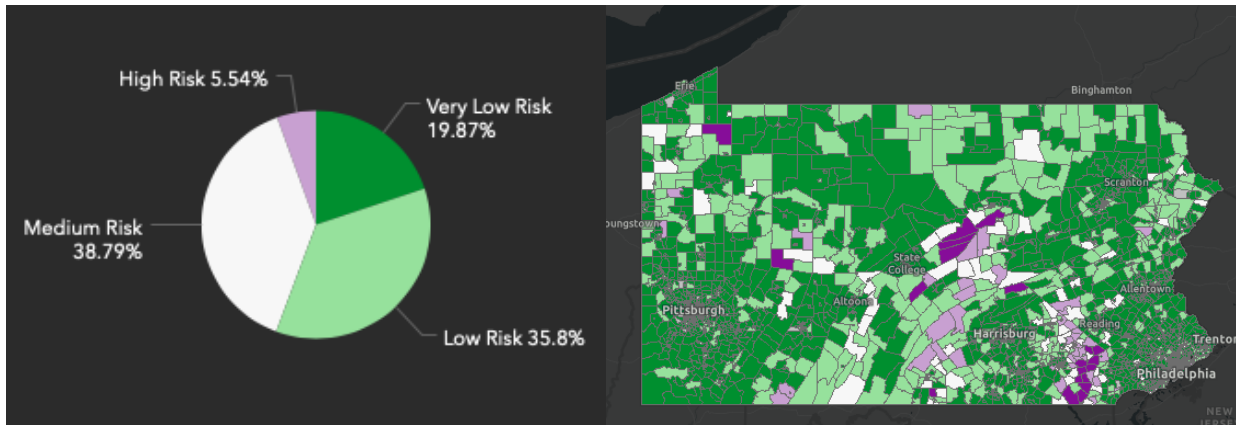
Figure 2: Social Determinants of Health Risk Index for Pennsylvania.

In addition, the SDOH Risk Index identifies the relative contribution to the overall risk score for each factor and by individual Census track, as shown in Figure 3.
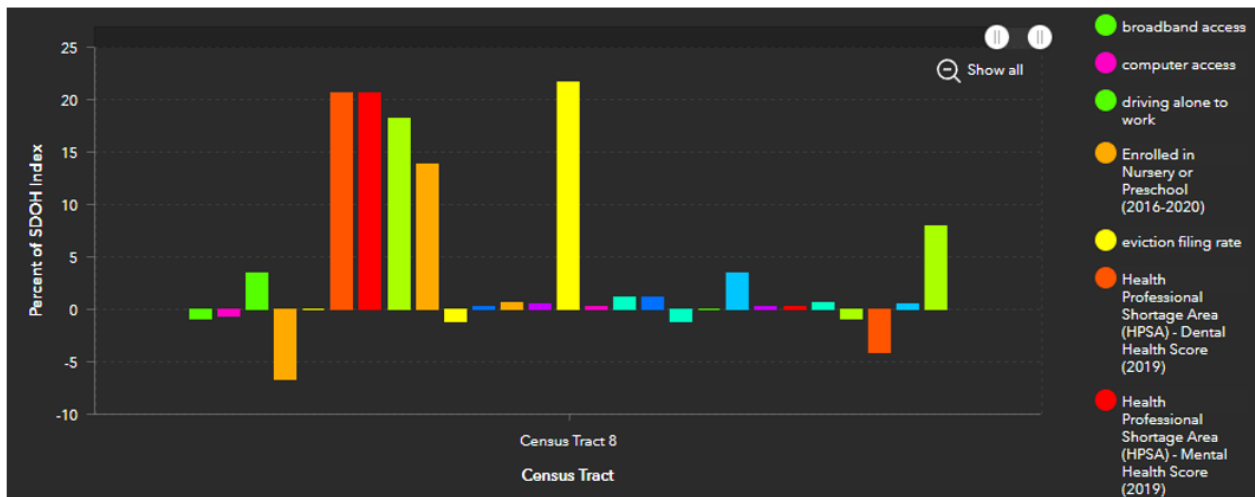
Figure 3: Contribution to overall Vulnerability Score of individual SDOH risk factors on a Census tract level.

The HSR.*health* SDOH Risk Index analyzes numerous socioeconomic variables, partially including family income, educational level, housing density, and race and ethnicity, among many others (partial listing shown in Figure 4) to investigate their relationships with health outcomes. The variables used in the SDOH Risk Index are a subset of the factors available for analysis through the GeoMD Platform, which number over 100. Appendix B includes a partial listing of the data sources used by the Platform.

Social Factor	Category	Social Factor	Category
Uninsured	Access to Care	Severe Housing Problems	Housing
Health Professional Shortage Area (HPSA) - Primary Care Score (2019)	Access to Care	Lead Paint Risk	Housing
Health Professional Shortage Area (HPSA) - Dental Health Score (2019)	Access to Care	Homeownership	Housing
Health Professional Shortage Area (HPSA) - Mental Health Score (2019)	Access to Care	Severe Housing Cost Burden	Housing
Highschool Diploma	Education	Housing Burden for Renters	Housing
Disconnected Youth	Education	Housing Burden for Owners	Housing
Low Education	Education	Computer Access	Housing
Some College and above	Education	Smartphone Ownership	Housing
Enrolled in Nursery or Preschool (2016-2020)	Education	Broadband Access	Housing
Chronic School absenteeism	Education	Median Home Value	Housing
Job Density (2016)	Employment	Median Gross Rent	Housing
Children in poverty	Income	Eviction Filing Rate	Housing
Federal Poverty Level	Income	Driving Alone to Work	Transit
Income Inequality (Gini Index) (2016-2020)	Income	long comute driving alone	Transit
Food Cost Insecurity	Income	Traffic Volume	Transit
Single Parent households	Family and Social Support	Public Transit	Transit
Residential Segregation	Family and Social Support	Housing Units with No Car	Transit
Violent Crimes		Respiratory Hazard Index	Air and Water Quality
Recreation and Green Space		Drinking Water Violations	
Food Accessibility / Food Desert			

Figure 4: Partial listing of social factors available in the GeoMD Platform and included in the SDOH Risk Index.

GeoMD End Users

Our solutions are multi-faceted and by their very core mandate, look at a multitude of variables to draw actionable conclusions. The supported end user community is equally as diverse. One such user, the Maryland Hospital Association, is leveraging the GeoMD Platform for Health Equity to assess the impact on patient health outcomes as well as health systems due to care deserts across primary care, maternal care, and pediatric care service lines.

The GeoMD Platform has provided insight into the medical supply needs on a per-health facility basis during pandemic and co-incident natural disaster (e.g., flood, landslide) scenarios. A presentation on this solution is available online.

In addition, our vision encompasses use by:

- Developer of Value Based Payment Arrangements.
  - Analytics that determine the impact of SDOH on specific health outcomes, including costs, can be utilized to risk-adjust populations when developing such payment models. In addition, it allows health systems under the TCOC paradigm to undertake targeted interventions toward the most significant social determinants that lead to the poor outcome of interest.

- Local and State Health Departments
  - By providing high level data into neighborhoods and communities in a given area, our products will assist professionals in local and state health departments to make more strategic decisions when deploying population-level interventions.

- Legislative Decision Makers
  - Legislators in healthcare committees are, by the nature of their positions, dependent on high level, politically unbiased information to make decisions regarding laws, regulations,

mandates, and budget allocation. Our solution provides this level of reliable, on-the-ground information.

● Hospital Quality and Performance Teams
  ○ Since the advent of the Affordable Care Act (ACA) in 2010, federal and private third-party payers have been demanding more from hospital performance. Quality teams who wish to have tools for constant surveillance of their catchment area, as well as actionable data for improvement initiatives, will be well served by this solution.

● State-wide Clinical Associations
  ○ Clinical associations such as the Maryland Hospital Association are always in the business of giving their membership the most up-to-date and actionable data to support and advance the standard of care for both clinical practices and operational decisions.

The GeoMD Platform for Health Equity meets these diverse needs and use cases.

GeoMD Use Cases

Here is a partial list of use cases supported by the GeoMD Platform for Health Equity.

1. **Identification of Vulnerable Populations**

   While we often know that inequity in health outcomes is present, it's more difficult to pinpoint exactly what populations are being affected by this inequity since there's variation through time and variation between localities. HSR.*health*'s GeoMD Platform allows stakeholders to clearly identify which communities are experiencing a chosen unequal health outcome and this is the first step in the planning for strategic interventions.

   Which neighborhoods have the highest COVID-19-associated admission rate within a given hospital system?

   Which areas of the State show where Hispanic women are at the highest risk for neonatal or infant mortality?

2. **Identification of Primary Factors Involved in Harm**

   In the same vein that vulnerable populations vary through time and place, the factors that are involved in creating inequity, also vary. The GeoMD Platform can parse out the social, economic, and environmental factors affecting a chosen outcome and allows for the creation of a hierarchy of needs so that strategic resource allocation can be carried out to tackle either the most influential risk factors or the most actionable risk factors.

   What are the main factors affecting Emergency Room utilization among patients with uncontrolled diabetes in a given county?

Of the many factors involved in high infant mortality rates in a given County, which factor is the most amenable to change?

3. **Quantifying the Risk of Negative Health Outcomes**

Due to the reality of limited health resources, it is often necessary to not only triage which factors are the most pressing in the creation of risk, but also which communities are the most at risk of deleterious health outcomes. The GeoMD Platform quantifies the risk between different vulnerable communities to enable strategic planning for potential interventions.

Among the elderly cohort across multiple counties, which one must drive the greatest distance to obtain daily medications?

In primarily African American neighborhoods, which factor is the most predictive for opioid abuse and overdose?

4. **Analyzing the Effect of Multiple Social Economic Factors on One Outcome**

Human health is complex and most health problems, if not all, are multifactorial in origin. The same applies for the vulnerability of communities at risk. It is rare that only one social factor is the primary driver for a certain outcome. HSR.*health's* GeoMD Platform identifies the primary factors and the combined risk of those factors. This assists with both understanding the complexity of the problem and developing strategic interventions.

How does housing and air quality combine to influence the risk of hospitalization for adults with uncontrolled COPD? What happens if you add race to the analysis?

Does transportation assistance create a measurable improvement in infant mortality in counties with no women's health clinics? What happens when you filter through English as a Second Language Status?

5. **Facilitate the Monitoring of Interventions Longitudinally Through Time**

Public health interventions are by nature large in scope and tend to take more time to exert their influence than interventions at the patient level. It is often necessary to track the effects of interventions through time to evaluate the effectiveness of population health programs. The GeoMD Platform helps with tracking outcome changes through time and how different social factors also change as they are targeted by outreach programs.

How does the introduction of mobile COVID-19 booster or Flu vaccine stations in low-income neighborhoods change COVID-19/Flu incidence rates over a 12-month period?

What happens to infant mortality among African American women in specific counties when supplemental income is provided to them monthly? What is the 1-year infant mortality rate? What is the 3-year infant mortality rate?

GeoMD Financial and Cost Saving Benefits

The methodical and analytical approach behind the GeoMD Platform for Health Equity is key to solving public health challenges, including Health Equity. Rather than treating health inequity as an amorphous mystery, the GeoMD Platform clearly delineates and quantifies where health inequity is present, who it is affecting, and how it is affecting them. The Platform then elucidates the surgical approach needed to eradicate these artificial inequities that continue holding Pennsylvanians back from their best and most fulfilling life.

As an example, in 2016, the nationwide medical cost associated with preterm birth was estimated to be $49,140 as compared to $13,024 for a term birth. (20) In 2020, there were 12,486 preterm births in Pennsylvania, and about 14.1% or 1760 of those preterm births were among American Indian/Alaska Native infants. The medical, educational, and productivity cost associated with preterm births in Pennsylvania is approximately $65,000, amounting to about $114,400,000 in costs for American Indian/Alaska Native families on an annual basis. (21)

Removing inequities related to childbirth alone will achieve significant savings for both families and healthcare payers.

The GeoMD Platform for Health Equity: Technical Description

A technical description of the GeoMD Platform is provided in this section.

Data

The GeoMD Platform provides access to:

- Social and Environmental Determinants of Health Data
- Population Demographics
- Healthcare facilities data
- and multiple other datasets

at national, state, and local levels. In addition, other publicly available and proprietary data of interest can be added to the GeoMD Platform. Data can be sourced from authoritative sources, as well as public and private sources. Full transparency on data sources and formats is provided.

Dashboards

The GeoMD Platform can be accessed through web-accessible, user-friendly Dashboards, such as shown in Figure 5 below. Dashboards can be customized to meet specific user needs and interests. The Dashboards can create interactive mappings of data and analytics at multiple geospatial scales (e.g., state-wide, County, City, ZIP Code, Census Tract, Hospital catchment area).

Dashboards enable exploration of the complex interaction between and among the data listed above, along with other data of interest, against health outcomes. Through exploration, the dashboards help to gain an understanding of the challenges to achieving health equity and adequate healthcare overall throughout the Commonwealth of Pennsylvania.
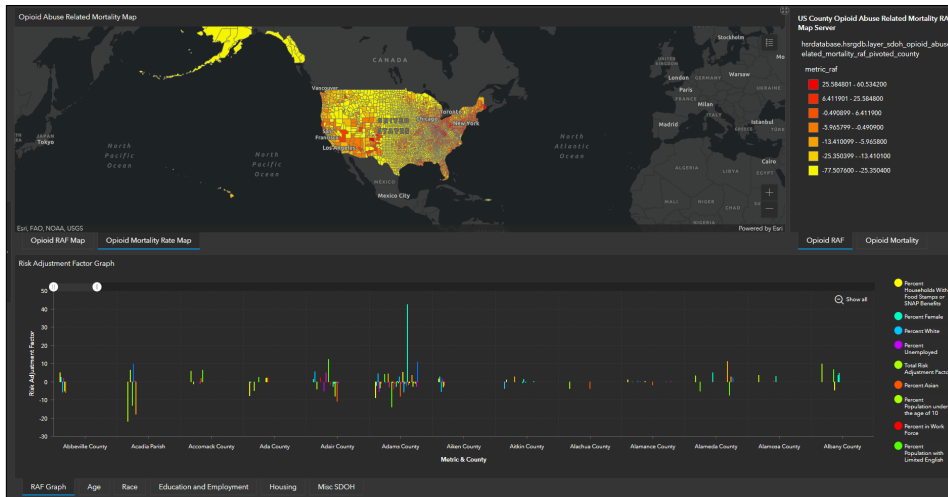
Figure 5: Opioid Abuse Related Mortality Risk Adjustment Factor Dashboard.

Risk Indices

Leveraging our geospatial technology, advanced ML/AI techniques, and novel public health models, the GeoMD Platform provides risk indices that solve key public health challenges, including but not limited to: health risk determinants and interventions, health equity, resource allocation, and prediction of disease spread and severity.

Infrastructure

The GeoMD Platform is built on the ESRI ArcGIS ecosystem and securely hosted on the AWS Cloud. The Platform's data is stored in a datalake in an AWS S3. The analysis of the data is conducted through a variety of robust data pipelines that incorporate event-driven lambda functions and athena queries supporting

broad data science and geospatial workflows. Other AWS components, such as Sagemaker and Sagemaker Geospatial, are also accessible.

The data pipeline as well as a collection of APIs supporting both open source and proprietary data sources and formats are used to import and export data.

Methodology

The GeoMD Platform is an AI-enabled, spatial data infrastructure that curates data globally and provides actionable risk insights throughout the healthcare ecosystem as well as to broader markets.

Our process leverages a multitude of geospatial analysis techniques, such as bi-variate cluster analysis, focal location quotient, spatial regression, and inverse distance weighting, among others, as well as machine learning and AI techniques, to identify the specific SDOH factors impacting health outcomes within particular regions and for specific subpopulations – allowing for targeted interventions.

The SDOH Risk Index provides public health authorities a simple and actionable vulnerability score at a granular level of the relative risk of poor health outcomes due to the present social factors. The SDOH Risk Index also identifies the impact on health outcomes, both positive and negative, from specific social factors. In addition, two or more SDOH factors can be combined so that their intersecting effect on a population can be revealed.

CONCLUSION

Health inequity, at national, state, and health system levels, continues to be an ever-present and pervasive challenge that impacts everything we do in clinical practice and public health policy. From chronic disease prevalence to COVID-19 transmission to the opioid crisis, profound inequities in both treatment, resource allocation, and outcomes present an ongoing challenge for a better quality of life for all citizens.

Pennsylvania faces a myriad of stark disparities and inequalities that significantly impact the health and well-being of its diverse population. These disparities manifest across various dimensions, from the disproportionate burden of COVID-19 cases and deaths among Black Pennsylvanians to the alarming rates of drug overdose fatalities. Additionally, the state grapples with limited access to healthcare services in medically underserved and rural areas, exacerbating health disparities, particularly for minority populations.

Childhood poverty rates, infant mortality, and maternal mortality also underscore the challenges faced by vulnerable communities in Pennsylvania, with Black Pennsylvanians experiencing higher rates of adverse outcomes. Mental health remains a critical concern, affecting a substantial portion of the population. The scarcity of specialized healthcare services and clinics across many counties further compounds the difficulties individuals face in accessing necessary care.

Tackling health inequity is at the core of every single analysis that we do at HSR.*health*. By the very nature of our methodology, our tools and analytical dashboards continually uncover and shed light on these inequities.

The importance of centering social and economic determinants of health in our tools cannot be understated. It is precisely the idea that SDOH are something "extra" to be looked at when there's more time or more money in the budget that fuels the continuation of these stark inequities across our nation.

It is necessary that we in the public health and healthcare community continually and habitually make it a point to include these analyses into the planning phase of health policy and health interventions. The same mindset needs to be adopted in clinical medicine as well, where too often diagnostic and treatment strategies are undertaken without a thought to pre-existing inequities that affect outcomes.

The advent of exciting new technologies such as artificial intelligence (AI) promise to change the way we look at health data and what actionable insights can be gleaned from them. As a leader in the field, HSR.*health* continually looks to ensure that technological innovation serves the greater good. Our geospatial analyses, powered by AI, are a source of continuous new insights that can allow strategic, surgical interventions by health and policy decision-makers.

Our organization, with a record of community involvement that stretches back for over a decade, strives to be the perfect collaborative partner for the Hospital & Healthcare Association of Pennsylvania to work with towards achieving health equity.

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Appendix A: Data Sources, Partial Listing

Table A1 below includes a partial listing of data sources used by the GeoMD Platform for Health Equity. Additional sources are curated on a regular basis.

Table B1: Partial List of GeoMD Platform for Health Equity Data Sources.

Data Sources	Data Sources
U.S. Federal Agencies	**U.S. State & Local Government**
Agency for Toxic Substance and Disease Registry	Baltimore City Health Department
Centers for Disease Control and Prevention	Maryland Behavioral Health Administration
Centers for Medicare and Medicaid Services	US State Departments of Health
Federal Emergency Management Agency	Maryland Governor's Office of Crime Control & Prevention
GeoPlatform	Maryland Vital Statistics Administration
Homeland Infrastructure Foundation-Level Data	Montgomery County Department of Health & Human Services
National Aeronautics and Space Administration	Maryland State Board of Elections
National Land Cover Database	Louisiana Department of Health
National Oceanic and Atmospheric Administration	Florida Department of Health
U.S. Agency for International Development	New York Department of Health
U.S. Bureau of Labor and Statistics	
U.S. Census Bureau	**International Governments**
U.S. Department of Health & Human Services	Abu Dhabi Department of Urban Planning and Municipalities
U.S. Department of Homeland Security	Dubai Health Authority
U.S. Department of Housing & Urban Development	Federal Competitiveness And Statistics Authority, U.A.E.
U.S. Department of Transportation	Ministry of Health, the Kingdom of Saudi Arabia
U.S. Forest Service	Oman National Centre for Statistics and Information
U.S. Geological Survey	China Centers for Disease Control
U.S. National Address Database	United Kingdom National Health Service
Non-Profit Organizations	Republic of Kenya Ministry of Health
National Association of Public Safety GIS Foundation	Namibia Ministry of Health
American Cancer Society	Republic of Niger Ministry of Health
American Heart Association	Democratic Republic of Congo Ministry of Health.
AmeriGEO	Seychelles Department of Health
Kaiser Family Foundation	Peru Instituto Nacional de Estadística e Informática
Robert Wood Johnson Foundation	Peru gob.pe Plataforma Nacional de Datos Abiertos
The Group on Earth Observations (GEO)	

Humanitarian Data Exchange	**International Organizations**
Our World in Data	UNICEF
GISAID	U.N. Office for Disaster Risk Reduction
Outbreak.info	The World Bank
COVID ACT Now	The World Health Organization
COVID Tracking Project	The WHO Africa Region
American Hospital Directory	Global Data Lab
Educational Institutions	Google
Dartmouth Institute	IHME
Stanford University	Doctors Without Borders
University of Maryland College Park	Christian Health Services Corps
Massachusetts Institute of Technology	Global Development Group
Johns Hopkins University	Open Street Maps
University of California Berkeley	USAID