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Health Spatial Information Framework White Paper

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i. Abstract

This Health Spatial Data Infrastructure white paper provides a discussion about the collection, exchange, integration, analysis, and visualization of health and non-health data to support health applications. Applications that address health issues at global and population level scale as well as at the local, individual patient scale are presented. The paper identifies opportunities to advance OGC Standards towards building a framework to support Health Spatial Data Infrastructures (SDIs).

ii. Keywords

The following are keywords to be used by search engines and document catalogues.

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iii. Preface

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iv. Submitting organizations

The following organizations submitted this Document to the Open Geospatial Consortium (OGC):

- Spatial Quest
- HSR.health
- Open Geospatial Consortium

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Chapter 1. Summary

This Health Spatial Data Infrastructure (SDI) white paper provides a discussion about the collection, exchange, integration, analysis, and visualization of health and non-health data to support health applications. Applications that address health issues at global and population level scale as well as at the local, individual patient scale are presented. This paper identifies opportunities to advance OGC Standards towards building a framework to support Health SDIs.

An SDI is defined as a framework of policies, institutional arrangements, technologies, data, and people that enables the sharing and effective usage of geographic information by standardizing formats and protocols for access and interoperability.

Developing a Health SDI based on open standards will help health data users and other stakeholders in the following ways:

- **Solution Providers** - to understand market needs and add value to services;
- **Market Participants** - to understand where OGC standards can be applied to support improved health outcomes;
- **Government and Institutes** - to understand market priorities surrounding the need and use of data in healthcare, and to design health-oriented SDIs;
- **Standards Organizations** - to understand opportunities to develop or improve standards to support health applications and the healthcare industry overall;
- **Researchers** - to have a foundation of elements for advancing research on SDIs and health-related applications using OGC Standards;
- **Health and Medical Researchers** - to understand geospatial analytics on health and social data sets, as well as understanding the causes and consequences of poor health outcomes that may be in need of further research towards identifying viable treatment options, in addition to advancing the research towards solutions to population health challenges;
- **Health Systems** - to understand how such a framework could contribute to clinician point-of-care decision support and be leveraged to improve patient care and overall population health;
- **Insurers** - to understand how geospatial analytics on health and social data sets can indicate long-term health risks of populations, as well as potential means of intervening on those risks.

More generally, Health SDIs must become a mainstream component of the world’s healthcare infrastructure not only because of the critical and central role that health - and good health - plays in human life, but also because it is the most expensive component of most countries annual budget. It is well known that the U.S. health system is unsustainable at 20% of its Gross Domestic Product (GDP), but it is also unsustainable in other countries at 11% of their GDP.

Finding solutions to reduce the cost of healthcare - in developed nations and elsewhere - is important. It may be important to realize that these solutions may not come from within healthcare, because healthcare industry advances are always more expensive than any medical technology, treatments, or pharmaceutical drugs they replace. Cost control in healthcare may have to come from the digital realm, for its ability to integrate health data with non-health and novel data sets allowing for quick diagnosis and identification of revolutionary new population health measures that identify cost drivers as well as their solutions.

A Health SDI as a platform for analyzing geocoded health data with social and environmental data and potentially new data sets not yet created is a natural fit, as this document will demonstrate.

1.1. Key Applications Areas

The paper builds on contributions from OGC Health Domain Working Group (DWG) members and is informed by OGC Health DWG sessions from 2012-2019, including Summits in 2016 and 2017. The OGC Health DWG provides a forum for discussion of key geospatial interoperability requirements, issues and potential solutions relating to the health domain. The following key application areas are addressed providing a broad scope of market requirements and functional areas:

- Climate-Health
- Healthy Aging
- Health in the Smart City
- Disaster Resilience
- Global Indicators
- Maternal Mortality
- Pandemic Response

1.2. Foreword

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Chapter 2. Introduction

One hundred and fifty years ago, Dr. John Snow demonstrated the value of spatial relationships by combining the locations of cholera deaths and water pumps to track the progress of an outbreak of this infectious disease back to its source. Today, Geographic Information Systems (GIS), computing, modeling, statistics, sensors, geospatial data and OGC web service standards are enabling powerful spatial analysis to support health and epidemiological research. However, there is not a documented framework that provides an architecture and interfaces to support a health spatial data infrastructure.

Discussions around the framework have been advanced by the OGC Health Domain Working Group (Health DWG). This DWG convened a Health Summit, during the OGC Technical Committee (TC) meeting in Dublin, Ireland in June 2016 [1]. Through interviews and discussion, participants indicated that a future state of an SDI would include implementation of more widely accepted interoperable standards-based technologies and services, improved privacy and security best practices, and common vocabularies.

Ideas from participants on the climate-health panel coalesced around the need to improve interoperability of geospatial data and web services to facilitate more sophisticated climate-health applications. Ideas from the healthy-aging panel coalesced around the ability of sensor networks to support active and healthy aging, connecting indoor sensors and devices to support clinical records and the wellbeing of patients with cognitive impairments (as an example) – this culminated in the creation of an Active and Healthy Aging Observation and Measurement (AHA O&M) Profile. Ideas from participants on the healthy urban environments panel coalesced around the need for well-defined protocols for using health information in mapping applications while protecting privacy, to better understand interaction between disease and health determinants, including social and environmental factors.

Since the Health Summit in 2016, interest continues to be expressed in the potential for OGC standards to support health domain requirements, helping to solve interoperability challenges for integrating health data with non-health data (commonly called social determinants of health or SDoH). But disparities remain in the adoption of standards and frameworks to collect, process, store, integrate, analyze, visualize, share, and protect information, especially within complex Big Data scenarios. Health professionals rarely or at best inconsistently have access to or are able to use, for example, climate and weather data for diagnosing, treating, monitoring, or advising a patient; or to take informed action based on environment and health data mashups, or to determine causal relationships over various spatial and temporal scales.

While it is recognized by the medical community that the environmental factors these data sources represent can impact health outcomes for a wide range of patient conditions (e.g., asthma, allergies, depression, isolation, stress, skin conditions, etc.), these data sources are not available with the same consistency and accuracy of other health data (e.g., lab results and patient vital signs). This complicates provider efforts to leverage this data to take informed action and to determine causal relationships over various spatial and temporal scales.

The data challenge includes several aspects: quantity of data, consistency of data availability, ability to customize data to meet diverse provider requirements, distributed nature of data, the heterogeneity and diversity of the data, the lack of data sharing due to both policy and technology limitations, and difficulties to share across disciplines, organizations, and geographic boundaries. The timeliness of the data is also a potential challenge. Healthcare Data must be available at the point-of-care and while care is being delivered. Data and information provided to the treating clinicians after treatment has been given is of much less utility. Data and information must also be synthesized into a directly actionable format – and provided within the clinical team's current workflow and processes.

Healthcare is a time-sensitive industry, data and data flows must accommodate those realities in order to be effective. Further, it is important to look at how geospatial standards are used to support indicators on a spatiotemporal basis to help determine current state and plan for action related to global disparities for health impacts from disasters and climate change. Challenges still remain on spatiotemporal understanding of health impacts (e.g. injury, illness, death) from climate change and environmental health determinants, population vulnerabilities and adaptive capacity, and other possible complex exposures (diets, lifestyles, etc.).

It is also worth noting that sometimes making more information available to the public can have unexpected collateral consequences. For example, identifying cities or neighborhoods with heightened risk to asthma patients could potentially cause real estate valuations in the area to fall.

This white paper, as well as potential future activities to advance the framework towards a Health SDI, will continue to be discussed at future Health DWG meetings and summits.

This paper first presents an introduction and background, then discusses key application areas, and finally proposes a framework to support Health SDIs. The resulting framework will serve as the basis for agencies around the globe to support regional SDIs and to develop prototype activities under the OGC Innovation Program for further refinement of framework capabilities.

There is also not a defined framework for how to use geospatial data analytics to derive potential solutions to population health challenges. That is a missing link towards which this white paper hopes to serve as a first step.

Chapter 3. Initiatives

Numerous initiatives (including standards and projects) within the health and geospatial domain can provide patterns and best practices for the building of a Health SDI. Several were reviewed for this purpose and are discuss below.

3.1. GEO Task US-09-01a Critical Earth Observations Priorities for Health Societal Benefit

Experts under the Group on Earth Observations (GEO) supported the development of a study to identify Earth Observations required to support a Health Societal Benefit Area (Health SBA) under Task US-09-01a [2]. The Health SBA was separated into three areas dealing with:

1. Air Quality – focusing on air pollutants that have damaging effects on human health
2. Aeroallergens – focusing on airborne substances such as pollen and spores
3. Infectious Disease – focusing diseases influenced by climate and environmental factors

Three teams documented requirements for Earth Observation in each of these areas.

3.2. EO4HEALTH

Earth Observations for Health (EO4HEALTH) is a community activity under the GEO 2017-2019 Work Program. Its goal is the advancement of integrated information systems to reduce environmental health related risks, focusing on:

- Weather and climate extremes (e.g., heat)
- Water-related illness (e.g., cholera)
- Vector borne disease (e.g., dengue, malaria)

An Implementation Plan for years 2020-2022 was developed in March 2019.

3.3. EO2 Heaven

EO2HEAVEN was funded by European Commission 7th Framework Program to advance understanding of the complex relationships between environmental changes and their impact on human health. The project advanced a system architecture and developed applications related to changes induced by human activities, with emphasis on atmospheric, river, lake, and coastal marine pollution. Recommendations on standards-based Spatial Information Infrastructure (SII) to support research of human exposure and early detection of infections were provided [3].

The project started on February 1, 2010 and ended on May 31, 2013 with results published in a publication called EO2HEAVEN - Mitigating Environmental Health Risks. The case studies that were examined were the impact of air quality on respiratory and cardiovascular diseases; relationship between industrial pollutant exposure and adverse respiratory outcomes; and the links between environmental variables and cholera.

3.4. CGDI

The Canadian Geospatial Data Infrastructure (CGDI) implements a framework for data sharing and data integration by using standard based technologies. It has adopted many specifications addressed by the OGC, the Federal Geographic Data Committee (FGDC), the World Wide Web Consortium (W3C), and the ISO/TC211 standards committee on Geographic Information/Geomatics in describing, publishing, visualizing, accessing and manipulating geospatial resources, such as Catalog services interface, Web Map Service (WMS), Styled Layer Descriptor (SLD), Web Feature Service (WFS), and Web Processing Service (WPS) among others. These services can be chained together to implement complex tasks by defining a workflow, as was done in a pandemic simulation in 2007 funded by GeoConnections – Natural Resources Canada and the U.S. Geological Survey (USGS).

The collaboration between different governmental entities ensures interoperability for the CGDI. The GeoConnection program's 3 phases, listed below, were completed as of 2015:

1. Establish and Build – to build the infrastructure of the CGDI
2. Evolve and Expand – focused on promoting the CGDI among user communities
3. Integrate and Sustain – developed the CGDI's policies and procedures for improving sustainability.

In 2015, an assessment was done to see how the CGDI presented data to various government agencies. The finding determined that there was an increased use in the CGDI but with only an 80% implementation success rate. The goal was to implement it to a full 100% success rate. In 2018, another study was conducted to establish the improvement potential of the CGDI. The results presented that many organizations were not using complete CGDI services. Going forward, many organizations will develop a workflow to incorporate CGDI into their data infrastructure.

In earlier work supported by the CGDI, a Health Representation XML (HERXML) schema was designed that consists of semantic, geometric, and cartographic representation of health data. HERXML enables web-based visual representation of health data to support, among other applications, policy makers and health planning efforts.

3.5. INSPIRE Human Health and Safety Data Specifications

The Infrastructure for spatial information in Europe has defined the Human Health and Safety theme, including technical guidelines for data specifications, as shown in Figure 1 [4]. INSPIRE is a directive of the European Union (EU) that has been implemented across the 27 current member countries of the EU; European Free Trade Association member countries Iceland, Norway, Switzerland, and Liechtenstein; as well as the non-member states of the United Kingdom, North Macedonia, Serbia, and Turkey.

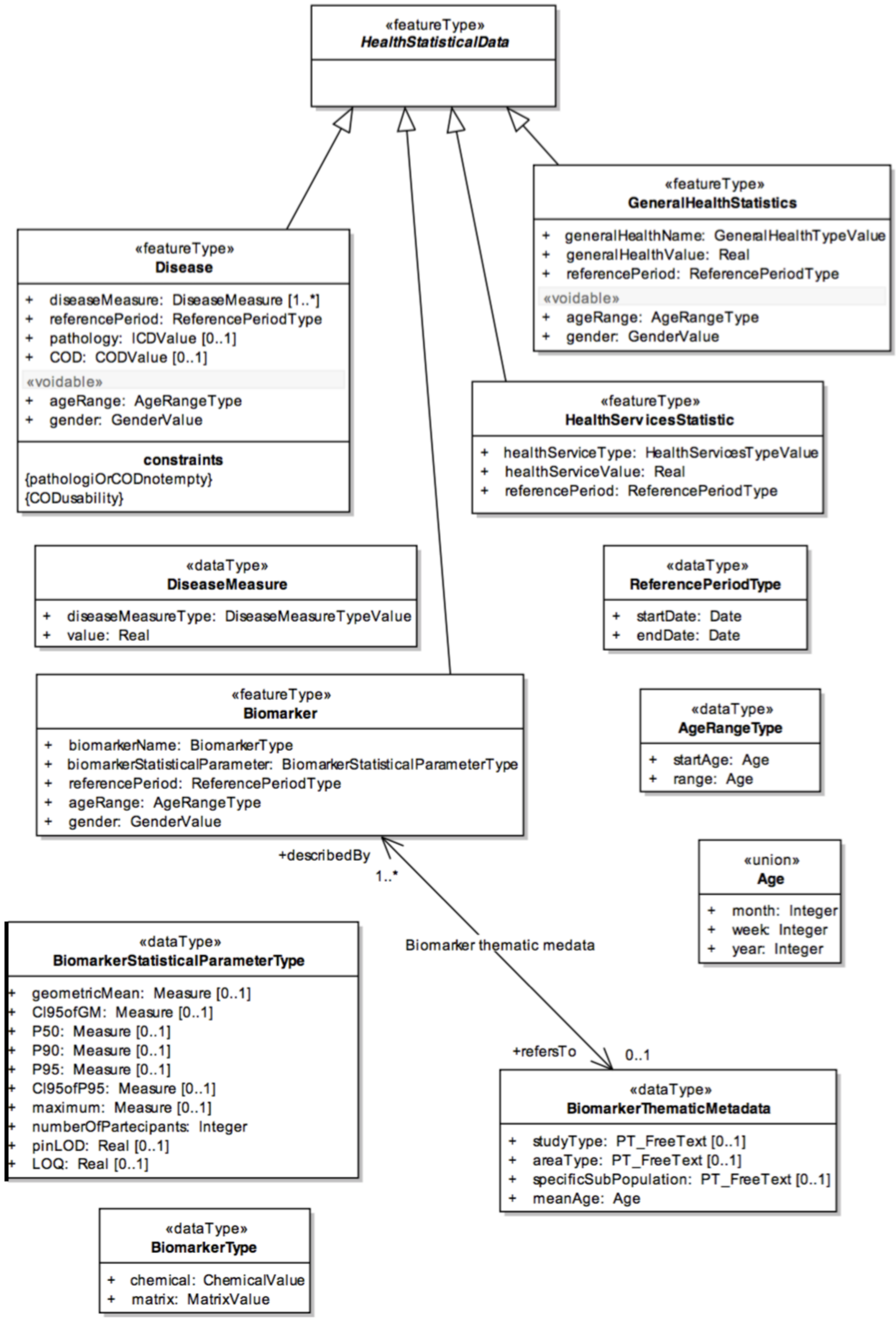

Figure 1. INSPIRE UML class for health statistical data

3.6. GEO-DARMA

The Data Access for Risk Management (DARMA) initiative aims to increase the availability and accuracy of risk related information to allow decision-makers to simulate the impact of risk reduction measures and make informed decisions about risk reduction investment. The type of risk information useful to decision makers depends on the geographical location, the type of risk affecting the region (e.g., weather, natural disaster, and rapid urbanization), local policies, and more. GEO-DARMA addresses several articles of the Sendai Framework such as articles 24 and 25 that call for the "promotion and enhancement through International cooperation, including technology transfer, (of) access to and use of non-sensitive data, information, as appropriate, communications and geospatial and space-based technologies and related services." GEO-DARMA will define end-to-end solutions fostering the use of accurate Earth Observation data risk information products and services for evidence-based decision making.

GEO-DARMA is one of the major initiatives that are supported by space agencies as a follow-on action to the Sendai Framework for Disaster Risk Reduction 2015-2030. Their long-term goal is to use EO data and EO-based risk information to increase awareness with donor agencies like The World Bank, and to foster the promise of EO solutions. There are 3 phases beginning with a Concept Phase and continuing to a Prototyping Phase, that aim to establish demonstrations in representative areas of the added value of using satellite data for multi-hazard Disaster Risk Reduction (DRR) in an international context. The third and final phase is an Operational Phase in which GEO-DARMA is a selecting on a case-by-case basis the projects to move towards operations based on their benefits to stakeholders and sustainability.

3.7. LODGD

The Linked Open Data for Global Disaster Risk (LODGD) group, as part of the interdisciplinary Committee on Data for Science and Technology (CODATA), aims to address the challenge of management and integration of disaster-related data for research and policy making. This Task Group has produced three white papers on this topic. In its first white paper publication [5], the group highlighted the importance of data interconnectivity from different scientific disciplines such as hydrology, meteorology, climate, civil engineering, land use, and public health. CODATA produced a second white paper, titled “Next Generation Disaster Data Infrastructure” stating the importance of developing an infrastructure that includes information systems and services that a region can depend on to gather, process, and display disaster data to reduce the impact of natural disasters [6]. A third expected white paper on “National Policy Study on Disaster Data around the World” was set to be published sometime in 2019.

3.8. IRDR-DATA

The Disaster Loss Data (DATA) project, under the umbrella of the Integrated Research on Disaster Risk (IRDR) program, brings together stakeholders from different disciplines and sectors to study issues related to the collection, storage, and dissemination of disaster of loss data. A white paper was published established the need of disaster data collection and a data base to visualize the data.

3.9. MeSH

The Medical Subject Headings (MeSH) is the US National Library of Medicine's thesaurus. It provides a controlled vocabulary of terminology useful for indexing and cataloging biomedical and pharmaceutical information.

3.10. SNOMED

The Systematized Nomenclature of Medicine (SNOMED) provides a comprehensive controlled vocabulary for terms related to anatomy, diseases, findings, procedures, microorganisms, substances, and other topics. It is used by the U.S. Federal Government systems for the electronic exchange of clinical health information.

3.11. UMLS

The Unified Medical Language System (UMLS) provides controlled vocabularies for biomedical information and health records. Useful applications that are built with UMLS can enable linking of records (via codes or terms) between doctor's, care centers, pharmacies, and insurance companies.

Chapter 4. Application Areas

The development of a Health SDI requires understanding the use cases the SDI should support. The following use cases are discussed in this document:

- Climate Health
- Healthy Aging
- Health in the Smart City
- Disaster Resilience
- Global Indicators
- Maternal Mortality
- Pandemic Response

4.1. Climate Health

Climate variability can pose significant threats to human health and well-being in the form of higher temperatures, increased extreme weather events, such as hurricanes and wildfires, decreased air quality, water shortages, and illnesses transmitted by food, water, and disease carriers such as mosquitoes and ticks. Extreme storms and temperatures can also disrupt the delivery of health services by causing damage to roads and transportation infrastructure, hospitals, clinics, wastewater treatment plants, and other facilities. Climate variability can also impact economic sectors that support health, such as energy, transportation, and agriculture.

As a case in point, there are many individuals in the U.S. who depend on electrically powered, life-saving medical devices, such as ventilators, cardiac devices, and home dialysis machines. These individuals depend on the medical devices to function properly, and therefore also depend on available and continuous electrical power. The U.S. Department of Health and Human Services (HHS) produces an emPOWER map (shown below in Figure 2) that provides a visualization by region (state, county, or ZIP Code level) as well as the specific number of people in tabular form of those who depend on such devices. For instance, the U.S. state of Georgia is home to 77,930 such individuals.

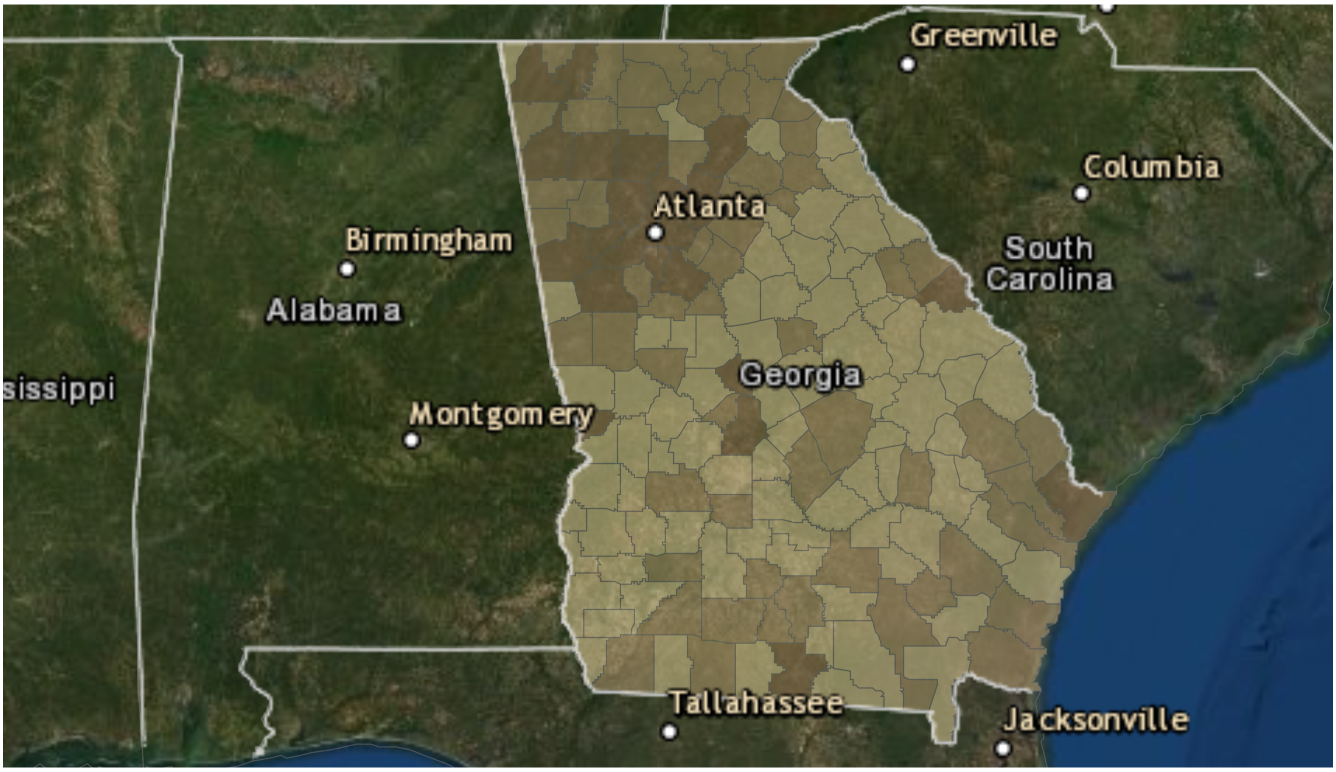

Figure 2. emPOWER map for the U.S. state of Georgia.

A Health SDI could help in the development of new ways to monitor, prevent, and respond to climate impacts on human health. Steps taken to prepare for climate impacts can improve health and provide other societal benefits, such as sustainable development, disaster risk reduction, and improvements in quality of life.

Applications arising from a Health SDI could help health authorities publish up-to-date maps showing various dimensions of disease, population health, and environment. Economies of scale can be leveraged when epidemiological research and health planning communities utilize a coordinated system to address inequalities in and stresses on health systems and healthcare provision, access, and promotion. Applications can be scaled up to support more sophisticated climate health, flood risk, and heat-event scenarios, particularly during health emergencies. The OGC Disaster Resilience pilot conducted in 2019 addressed these scenarios in part [7].

Research collaboratives such as the Lancet Countdown can also inform framework development. The Lancet Countdown tracks the world's response to climate change and health benefits that may emerge from this response. This reporting is done annually, and different indicators are evaluated and changed as needed [8]. The Countdown proposes five thematic breakdowns:

- Climate change impacts, exposures and vulnerability;
- Adaption planning and resilience for health;
- Mitigation action and health co-benefits;
- Economics and finance; and
- Political and broader engagement.

These thematic breakdowns, along with associated indicator domains, could be used to provide organizing principles for a health SDI or perhaps even for the overall spatial information framework itself. There were 40 indicators in 2017. In 2018, a revision of the indicators led to the inclusion of a new indicator under the Public and Political Engagement breakdown called Corporate Sector Engagement in Health and Climate Change. The list of indicators from 2017 and 2018 appear in the Appendix.

4.1.1. Paris Agreement on Climate Change

The Paris Agreement on Climate Change was held in December 2015, at the 2015 UN Climate Change Conference (CoP21), held in Paris, France [9]. It highlighted that mitigating Green House Gas (GHG) emissions and air pollution can reduce health impacts and costs. There will be a global assessment every 5 years to assess the collective progress toward achieving the purpose of the agreement and to inform other parties of individual actions.

4.2. Healthy Aging

Some populations are more vulnerable than others to changes in health status. Vulnerable populations of concern include children, pregnant women, those with low income, immigrant groups, indigenous peoples, communities of color, as well as older adults. It is well known that the bulk of the healthcare expenditure goes towards care for senior populations. In the U.S., 36% of healthcare spending is attributed to the 65 and over population, even though they make up only 16% of the U.S. population.

In order to address and reduce the vulnerability of aging populations, health organizations are increasingly turning to geospatial analysis to assess and prioritize areas for intervention based on location.

Additional efforts to enable healthy aging were discussed in the Health DWG Summit in 2016 and include, for example, efforts that can take advantage of indoor sensors to improve the mobility of elders. Further details are available on the DWG’s Wiki page.

4.2.1. Geospatial Tech to Address Costs

Geospatial tools linking social determinants of health (SDoH) with health conditions, outcomes, and costs associated with the elderly can identify those social factors that are root causes of or influencers of poor health outcomes, and their associated high costs. Identifying root causes of poor health outcomes of the elderly populations will allow health systems, working within their communities, to address the underlying social factors and achieve improved health and quality of life for those communities.

4.2.2. Mobility and Ease of Access

Mobility and simply “getting around” are often reported as challenges for the elderly population. Limited mobility often leads to isolation, which in turn can cause and exacerbate many health conditions. Geospatial technology can address mobility issues in part by assessing and rating parks, public areas, and internal building structures on ease of mobility, such as the presence or absence of elevators, hand-rails on stairwells, ramps in place of steps for short elevations, as well as other health-related issues such as mold, temperature, air quality, etc.

Geospatial technology can also identify gradations in topology and elevation in public parks or city-wide areas to provide information on walking tracks.

4.3. Health in the Smart City

Growth in the proportion of urban residents making up the global population can impact environmental sustainability, the availability and effectiveness of public services, economic growth and social resilience. Effective integration of human, physical, and digital systems would enable cities to be more prosperous, sustainable and resilient.

The World Health Organization (WHO) Healthy Cities project brings together hundreds of cities under its network to make health a priority on economic, social, and political agendas. Boulus and Al-Shorbaji [10] discussed the importance of Internet of Things (IoT) and geospatial analytics empowering healthy city decisions. One example is the wireless sensors connected to garbage bins to monitor trash levels in Barcelona. This not only provides data for optimization of data collection but can help minimize pollution and sanitation related illnesses. One could theorize that trash routes could be optimized to address the heaviest use garbage bins and best avoid any overflow. Overflowing waste containers can cause bacteria to grow, pollute air and water sources, and cause respiratory diseases, salmonella, and fever among others.

Mobile Health in an information technology field that advances the use of mobile devices to support health services and information. Information from mobile health and smart cities can improve healthcare and overall quality of life.

Smart Cities provide an exciting opportunity to continue and further drive advancements in the delivery of public services improving human life. Distributed Internet-of-Things and Internet-of-Medical-Things sensors on wearables, mobile medical devices, and even perhaps implantables together with a Smart City infrastructure allow for new means of gathering data on all aspects of life-in-the-city and provide health systems new and innovative means of responding to the specific needs of individual patients.

As another example, a Smart City can provide real-time monitoring of occupancy levels of inpatient and emergency room hospital beds, current stock of key medical supplies, and current clinical staffing levels at hospitals and other healthcare facilities, as well as contact tracing. Contact tracing has emerged as a crucial capability for tracking and controlling the transmission of an infectious disease, especially as the alternative being to lock down entire communities. The sensor infrastructure of a Smart City can allow not only tracking movement of a potentially infected individual, but also the identification of everyone who may have either come into direct contact with that individual or have been where that individual was and therefore possibly exposed to the disease.

This also demonstrates the integration of indoor location models with sensed occupancy data leveraging the IndoorGML and SensorThings API standards. This information can aid in balancing patient counts such as from emergency ambulance transport and, further, can be used by emergency medical services providers, such as 911 systems, to direct patients to the hospital with the clinical staff best suited to treat the patient’s current condition. Up-to-date information on the status of medical facilities will also aid in transferring patients between facilities. Enhanced visibility can also predict when medical supplies will run out, based on current stock and anticipated patient census, to automatically re-order supplies to ensure a safe, minimum level of supplies remain available. Also, such monitoring and visibility will aid in balancing patient counts during non-disaster scenarios for hospitals with overlapping service delivery areas.

Emergency and disaster response efforts will also benefit as Emergency Operations Managers will have knowledge of the specific medical supplies, clinicians, and pharmaceuticals to send and to where – greatly improving Emergency Medical Responders ability to provide medical care during a disaster.

Leveraging Smart Cities for health applications can be a key step in advancing OGC standards towards building a Health Spatial Data Infrastructure (SDI) that can be applicable to broad healthcare applications, including health system cost reduction efforts, disaster response scenarios, as well as improved health infrastructures in smart cities.

4.4. Disaster Resilience

Natural and man-made disasters pose significant threats to human health in numerous ways – loss of housing, contamination of the food and water supplies, decreased air quality, exposure to pollutants, general environmental degradation, damage or force the closure of roads, airports, and other transportation infrastructure, as well as other potential impacts. Disasters can also disrupt the delivery of health services by damaging or causing the closure of hospitals, community clinics, and pharmacies or making them unavailable due to unpassable roads. An often-overlooked consequence of this is the reduced availability of prescription drugs. For many individuals, even a 1-3 day gap in medications can lead to significant and life threatening health complications. As of 2017, over 60% of Americans were on daily medications for one and often multiple chronic conditions. Therefore, maintaining channels for healthcare delivery needs to be a key part of an emergency response capability.

A Health SDI can support disaster resilience effort by leveraging OGC standards and geocoding health data for secure sharing among appropriate emergency response team members, health complications can be avoided, and lives can be saved that may otherwise be lost to the disaster.

A Health SDI can identify and bring together data that can potentially aid disaster response effort, including:

- Data on health outcomes, costs, incident rates of illnesses, and data from health industry repositories such as Registries, Electronic Health Records systems, Prescription Drug Monitoring Programs, or State Health Information Exchanges, etc.
- Also included are data on the relevant Social Determinants of Health (SDoH) that together with health data can help to define the baseline health posture of the community prior to the disaster. SDOH partially include: population, population density, age, gender, race, ethnicity, education, employment, income, insurance (uninsured, public, private), transportation networks, locations of healthcare facilities, incident rates of, illnesses, food insecurity, housing challenges (e.g., levels of affordable housing, levels of homelessness), location of head start programs, social media data (e.g., Twitter).
- Key health indicators, that along with SDoH can establish a baseline health posture throughout the affected region. Health indicators can also help determine both the extent of the disaster impact on health as well as the region’s recovery after the disaster. Relevant indicators include the density of community health workers, physicians, and pharmacy personnel, incident and death rates due to illnesses attributed to or spread through contaminated air, water, and food

supply, and other indicators relevant to the disaster scenario.

- Relevant disaster-related data that details what's actually happening in the disaster can serve as input to this effort to understand the impact on health. For example, in a Flood scenario, this can include data on flood path and forecasts, flood/water level, reports of flood-related power outages, building (e.g., hospital, pharmacy) closures, as well as disaster-related injuries, illnesses, and deaths received via existing Disaster SDIs, such as GEOGLOWS and other sources. However, a Health SDI as discussed here can be generally applicable to general to establishing a healthcare capacity in an emergency response scenario and applies broadly to natural (e.g., flood, wildfire, winter storm, pandemic etc.) or man-made disasters.
- Workflow for leveraging the above data through all phases of the recovery effort, from collecting and receiving the above health and disaster-related data and information, processing that information in a health context, making real-time decisions on healthcare delivery needs for the affected population and geographic areas, and communicating that information to the appropriate members of the disaster response team and ultimately to the clinical point-of-care – all in a format that can be actionable by on-the-ground emergency response and medical personnel.

A disaster response effort will be benefited by well-defined protocols for using health information in mapping applications while protecting privacy, to better understand the impact to human health caused by the disaster, as well as to understand the health interventions and responses needed to address that impact among the displaced and affected population. Applications arising from a Health SDI will help emergency response teams and health authorities publish up-to-date maps showing various dimensions of the disaster, such as disease prevalence or outbreak, changes to population health, and potentially the identification of baseline healthcare services that should be provided to all displaced members of the population. Economies of scale can be leveraged when all members of a disaster response team – both teams on the ground, as well as support teams away from the disaster site(s) utilize a coordinated system to address inequalities in health care provision, access, and promotion. Applications can be scaled up (down) to support larger (smaller) disaster scenarios, such as by geographic region and/or population size impacted.

4.4.1. Sendai Framework for Disaster Risk Reduction

The U.N. General Assembly Resolution A/RES/71/276 endorsed the recommendations of the Open-ended intergovernmental expert Working Group on 2 February 2017. The report recommends indicators for the seven global targets of the Sendai Framework for Disaster Risk Reduction 2015-2030. The indicators related to health are as follows:

Sendai Framework Indicators Related to Health

- Global target A: Substantially reduce global disaster mortality by 2030, aiming to lower average per 100,000 global mortality between 2020-2030 compared with 2005-2015.
    - A-1 (compound) Number of deaths and missing persons attributed to disasters, per 100,000 population.
    - A-2 Number of deaths attributed to disasters, per 100,000 population.
- Global target B: Substantially reduce the number of affected people globally by 2030, aiming to lower the average global figure per 100,000 between 2020-2030 compared with 2005-2015.

    - B-2 Number of injured or ill people attributed to disasters, per 100,000 population.
    - B-3 Number of people whose damaged dwellings were attributed to disasters.
    - B-4 Number of people whose destroyed dwellings were attributed to disasters.
    - B-5 Number of people whose livelihoods were disrupted or destroyed, attributed to disasters.
- Global target D: Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030.
    - D-2 Number of destroyed or damaged health facilities attributed to disasters.
    - D-7 Number of disruptions to health services attributed to disasters

However, the quality of these indicators is constrained by the quality of the data against which they are generated. When high-quality data is accessible, differences in recording can frustrate attempts at aggregation, and even when aggregation is possible, significant subgroup trends can sometimes be masked. As the authors note, the World Health Organization (WHO) Global Reference List of 100 Core Health Indicators is a step toward alignment in reporting. A Health SDI should take advantage of the momentum established by these 100 indicators.

A complementary asset is available from the Global Burden of Disease (GBD) research program. The GBD provides a helpful decision-support tool, the GBD Visualization Hub, particularly with respect to Sendai Framework Global Targets A and B. The Hub is maintained by the Institute for Health Metrics and Evaluation (IHME) at the University of Washington in Seattle, USA. It provides consistent, comparative descriptions of the burden of diseases and injuries (and associated risk factors), including categorization of deaths and disability adjusted live years due to a breadth of causes.

Another complementary tool is provided by INFORM (INdex FOr Risk Management), a global, open-source risk assessment for humanitarian crises and disasters. It can be used to support decisions about prevention, preparedness and response. Of particular note are the data and calculation steps showing:

- Risk of humanitarian crises and disasters;
- 5-year trends in risk;
- Where has risk increased most; and
- Prioritization using risk level and trends.

4.5. Global Indicators

Various global initiatives have provided guidance towards global indicators to help monitor the status of health in populations. The initiatives include Sustainable Development Goals (SDGs) developed by the U.N. and the Sendai Framework for Disaster Risk Reduction.

4.5.1. United Nations Sustainable Development Goals

At the U.N. Sustainable Development Summit 2015, 193 countries agreed on the SDGs. For each goal specific objectives and targets were defined. The goal related to health is `Goal 3 Good Health and Wellbeing`. The objective of this goal is to "Ensure healthy lives and promote well-being for all at all ages". Thirteen targets and associated indicators were developed by the Interagency and Expert Group on SDG Indicators (IAEG-SDGs).

Indicators for the Sustainable Development Goal 3 Good Health and Wellbeing

```
3.1.1 Maternal mortality ratio
3.1.2 Proportion of births attended by skilled health personnel
3.2.1 Under-five mortality rate
3.2.2 Neonatal mortality rate
3.3.1 Number of new HIV infections per 1,000 uninfected population, by sex, age and
key populations
3.3.2 Tuberculosis incidence per 100,000 population
3.3.3 Malaria incidence per 1,000 population
3.3.4 Hepatitis B incidence per 100,000 population
3.3.5 Number of people requiring interventions against neglected tropical diseases
3.4.1 Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic
respiratory disease
3.4.2 Suicide mortality rate
3.5.1 Coverage of treatment interventions (pharmacological, psychosocial and
rehabilitation and aftercare services) for substance use disorders
3.5.2 Harmful use of alcohol, defined according to the national context as alcohol per
capita consumption (aged 15 years and older) within a calendar year in litres of pure
alcohol
3.6.1 Death rate due to road traffic injuries
3.7.1 Proportion of women of reproductive age (aged 15-49 years) who have their need
for family planning satisfied with modern methods
3.7.2 Adolescent birth rate (aged 10-14 years; aged 15-19 years) per 1,000 women in
that age group
3.8.1 Coverage of essential health services (defined as the average coverage of
essential services based on tracer interventions that include reproductive, maternal,
newborn and child health, infectious diseases, non-communicable diseases and service
capacity and access, among the general and the most disadvantaged population)
3.8.2 Proportion of population with large household expenditures on health as a share
of total household expenditure or income
3.9.1 Mortality rate attributed to household and ambient air pollution
3.9.2 Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene
(exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services)
3.9.3 Mortality rate attributed to unintentional poisoning
3.a.1 Age-standardized prevalence of current tobacco use among persons aged 15 years
and older
3.b.1 Proportion of the target population covered by all vaccines included in their
national programme
3.b.2 Total net official development assistance to medical research and basic health
sectors
3.b.3 Proportion of health facilities that have a core set of relevant essential
medicines available and affordable on a sustainable basis
3.c.1 Health worker density and distribution
3.d.1 International Health Regulations (IHR) capacity and health emergency
preparedness
```

There are additional health-related goals and indicators addressing poverty, education, food / nutrition (malnutrition), food supply, water / vector borne disease, mental health, and occupational health and safety.

Each country will be able to measure progress toward achieving the objectives using the indicators.

Health indicators at the national and sub-national level consist of data obtained by national health agencies, statistical agencies, e.g. the U.S. Census Bureau, and national and regional health authorities. Lack of availability at the local levels constrains the ability to measure indicators for all regions. There are also challenges with integrating, analyzing, and visualizing indicator data at a sub-national level (at various scales) by countries adopting the indicators due to inconsistencies in data collection and the definition of medical terms. A case in point is Maternal Mortality, which is the first of the SDG's health indicators.

4.6. Maternal Mortality

Maternal mortality is a significant public health issue and a strong indicator of a nation's health status both nationally and internationally. The death of a mother has lasting consequences on family members and the larger society, ultimately representing one of the largest failures of a nation. The U.S. leads the developed world in its rates of both maternal and infant mortality. One of the issues the U.S. faces in its efforts in improving maternal care is the quality of data surrounding the incidents of maternal and infant mortality in the first place. The U.S National Vital Statistics System (NVSS) is the source of official maternal mortality statistics used for both subnational and international comparisons. However, this database utilizes statistics for which there is no gold standard in how death records are reported or collected.

Until the early 1990s, there was no systematic way to collect maternal mortality data in the country. Pregnancy-related death classifications were limited to a narrow classification listed on death certificates at the time, i.e. complications of pregnancy, childbirth, and the puerperium. The certificates used by states collected no information on whether a woman was pregnant at the time of death or had recently given birth. This means that the deaths which occurred during pregnancy for non-obstetric causes, like, high blood pressure or depression, as well as those that happen after birth, were not counted as maternal related deaths under local level reporting.

Death registration is based on state law where death certificates are filed and maintained in the state vital statistics offices. The states have recommended the use of the U.S. Standard Certificate of Death, which is revised once every 10 years in collaboration with states, National Center for Health Statistics (NCHS), and other federal agencies and subject matter experts. However, each state issues its own death certificate. States like West Virginia didn't even introduce a pregnancy classification on their death certificates until 2017.

U.S. states continue to have different mechanisms for reporting maternal deaths. The very information on the death certificate is provided by two groups of persons: 1) the certifying physician, medical examiner, or coroner and 2) the funeral director. The cause of death, critical in understanding and responding to maternal and infant mortality, is supplied by either the certifying physician, the medical examiner, or the coroner.

However, state-by-state data is reviewed by Maternal Mortality Review Committees (MMRCs)—review groups in only around half of U.S states. Their role is to filter through the death certificates to determine if the cause of death is pregnancy or child-birth related, at times without access to the patient's complete medical record. Each state then sends their statistics to the U.S. Centers for Disease Control and Prevention (CDC), who produce and release national-level data, after their own epidemiologists review the data to assess cause of death. While the review committee is a great step towards ensuring quality control, the official CDC data are not updated to reflect the findings of the committees, which means the national numbers on record aren't just likely to be inaccurate—they are known to be wrong. Additionally, copies of the matching birth and fetal death certificates are sent – if they can be matched.

Producing reliable data on maternal mortality should not be an issue considering growths in the field of technology and healthcare. Yet for some reason, quality assurance and reporting methodologies remain a challenge. When conducting a review of the literature, we find that there is no consensus in reported death rates on a national level, with the reported range being quite large. The U.S. maternal mortality rate, considered to be 23.8 deaths per 100,000 live births, is anywhere between a range of 16 to 26.5 maternal deaths. Failure in producing an official maternal mortality rate stunts prevention effort.

The U.S shares its reporting challenges with Mexico, a country where misclassification of the cause of death is a major component of the maternal mortality problem. In fact, in Mexico, no single number exists for its maternal mortality rate. Because of the inconsistencies in reporting, the rate is a range, as shown in Figure 3 below. It is no coincidence that the United States parallels Mexico's maternal mortality rates.

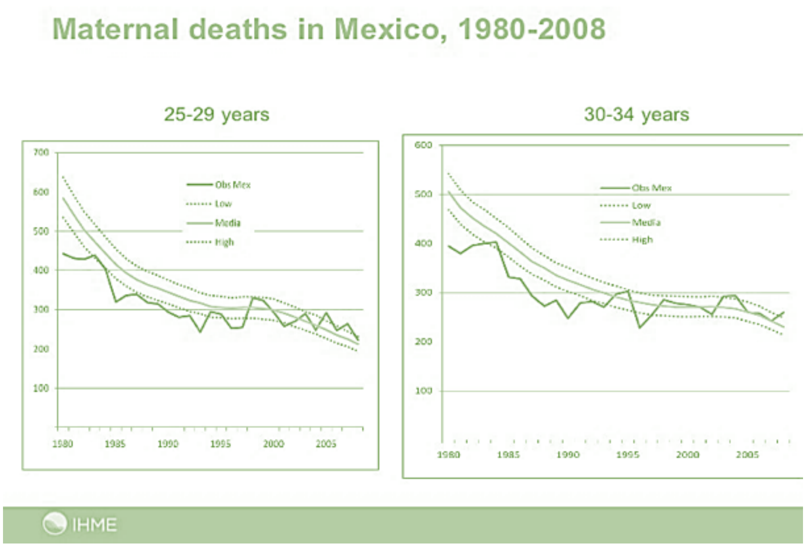

Figure 3. Maternal Mortality in Mexico.

The different reporting methods and standards make it challengingly difficult to integrate all reported data to develop one concise, accurate view of Maternal mortality or any health indicator. This makes it nearly impossible to learn the posture of the overall health & wellbeing of a nation. If the United Nations Sustainable Development goals are to be successful, a necessary start would be to have a detailed and universally consistent reporting on the medical conditions underlying the indicators.

Currently, without a universal standard for reporting, healthcare systems lack in uniformity with respect to reporting requirements. This can lead to challenges in patient care, confusion in expectations, the inability to communicate lessons learned and adopt best practices, which can lead to decreased national health posture. This can be easily seen through Maternal Mortality reporting, as the process of reporting deaths is significantly different both between and within countries.

4.7. Pandemic Response

The most well-known pandemic of the last Century, as well as the most devastating in terms of both loss of life and economic costs was the Spanish Flu of 1918. However, the world has experienced a handful of pandemics since (see the table below) and as human mobility and interconnectedness grows, the ability for a novel viral strain to spread across the globe and infect populations with no previous immunity grows exponentially.

Table 2. Pandemics since 1918.

Starting year	**Event**	**Geographic extent**	**Estimated direct morbidity or mortality**	**Estimated economic, social, or political impact**
2015	Zika virus pandemic	76 countries	2,656 reported cases of microcephaly or central nervous system malformation (WHO 2017)	US$7 billion—US$18 billion loss in Latin America and the Caribbean (UNDP 2017)
2009	Swine flu (H1N1) influenza pandemic	Global	151,700-575,500 deaths (0.2-0.8 per 10,000 persons) (Dawood and others 2012)	GDP loss of US$1 billion in the Republic of Korea (Kim, Yoon, and Oh 2013)
2003	SARS pandemic	4 continents, 37 countries	8,098 possible cases, 744 deaths (Wang and Jolly 2004)	GDP loss of US$4 billion in Hong Kong SAR, China; US$3 billion-US$6 billion in Canada; and US$5 billion in Singapore (Keogh-Brown and Smith 2008)
1968	Hong Kong flu influenza pandemic	Global	1 million deaths (2.8 deaths per 10,000 persons) (Mathews and others 2009)	US$23 billion—US$26 billion direct and indirect costs in the United States (Kavet 1977)

Starting year	Event	Geographic extent	Estimated direct morbidity or mortality	Estimated economic, social, or political impact
1957	Asian flu influenza pandemic	Global	0.7 million—1.5 million deaths (2.4—5.1 deaths per 10,000 persons) (Viboud and others 2016)	GDP loss of 3 percent in Canada, Japan, the United Kingdom, and the United States (McKibbin and Sidorenko 2006)
1918	Spanish flu influenza pandemic	Global	20 million—100 million deaths (111-555 deaths per 10,000 persons) (Johnson and Mueller 2002)	GDP loss of 3 percent in Australia, 15 percent in Canada, 17 percent in the United Kingdom, 11 percent in the United States (McKibbin and Sidorenko 2006)

Adding to this list, on March 11, 2020, the World Health Organization (WHO) declared the outbreak caused by the novel strain of Coronavirus, which emerged in late 2019 and is known officially as COVID-19, as a pandemic [11]. National and international response to this pandemic have included international travel restrictions, the cancelation of nearly all large gatherings of people across the globe including public, entertainment, and sporting events – as well as religious pilgrimages and Sunday Mass at the Vatican, as well as the quarantine and social isolation of over a billion people across a majority of the world's countries. Addressing COVID-19 will require concerted effort from government at all levels, the private sector, as well as the public.

The Health Risk Index discussed above that was developed through the Open Geospatial Consortium's Disaster Resilience Pilot and supported by U.S. Federal Emergency Management Agency (FEMA), is an example of an application that resides on a Health SDI that can aid a pandemic response. By leveraging the diverse sets of data within an SDI's library, the Health Risk Index can track the Transmission Risk of the pandemic to help Predict the next Hot Zones and Outbreaks of Coronavirus at the County and ZIP Codes levels within a country (pictured here for the U.S.) as well as Globally. The prediction can leverage data such as:

- Current cases
- Disease progression
- Population health conditions (e.g., age, chronic illness)
- Human mobility (e.g., transportation hubs, population and business centers)

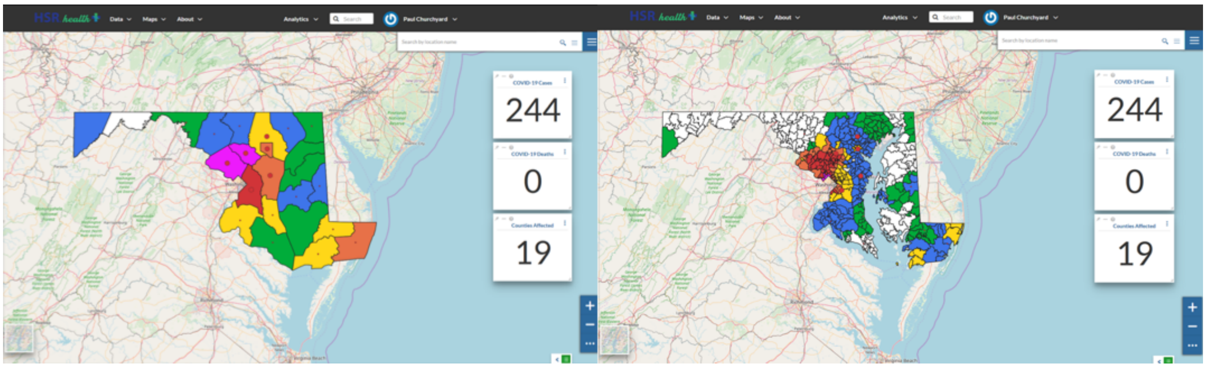

Figure 4. Maryland County and ZIP Code COVID-19 Transmission Risk Index as of 11:59pm EST 3/22/2020.

A Transmission Risk Index will enable deployment of medical resources in advance of the virus, rather than chasing the virus, and can significantly improve the ability to halt the spread of the contagion and treat the infected.

In addition, such an index can also guide eventual De-Quarantine efforts, allowing the resumption of normal daily and economic activity in ‘safe’ zones – or at least zones with the least risk of a ‘second bump’ of Coronavirus cases once social interaction is resumed. Speeding the safe resumption of normal economic activity will benefit the economy, as well as reduce the risks of mental health issues associated with social isolation.

The Health Risk Index can also provide guidance on where risk or mortality from the novel Coronavirus is high at multiple geographic resolutions (and shown in Figure 5 for the U.S.). By considering the underlying health status of the population, available medical resources, potential supply chain disruptions for medical equipment and resources, a Mortality Risk Index can be established that identifies both where emergency medical facilities and resources are needed as well as what contingencies need to be established to address shortcomings.

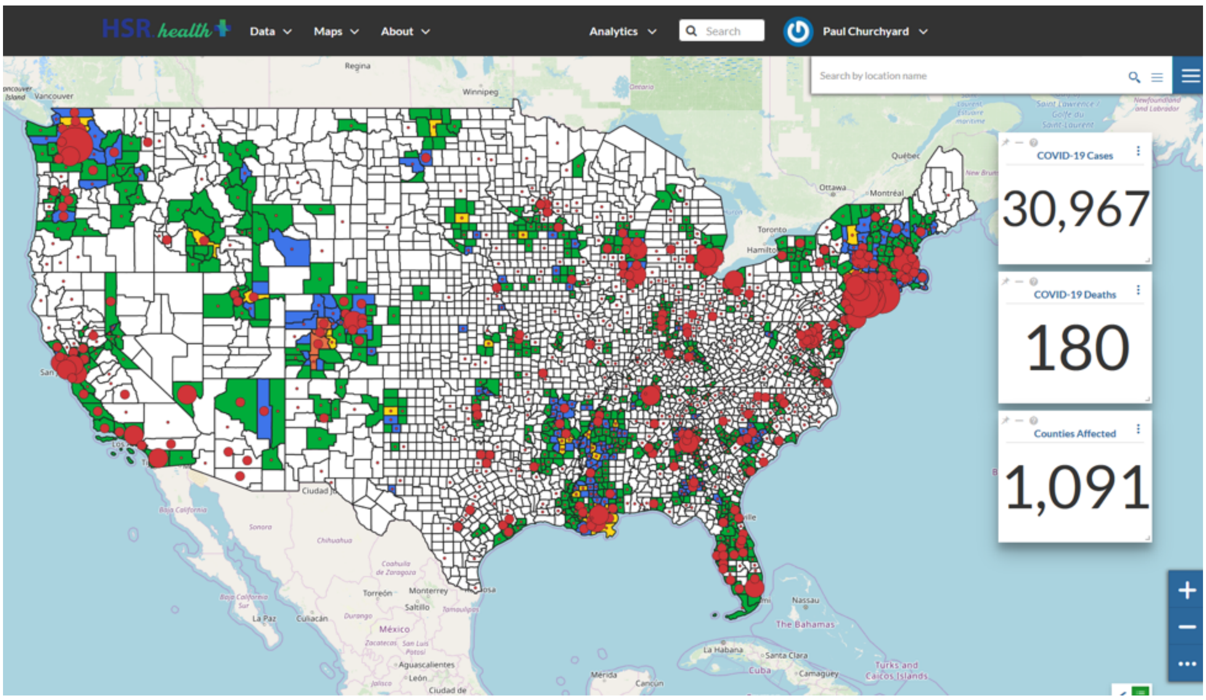

Figure 5. COVID-19 Mortality Risk Index as of 11:59pm EST 3/22/2020.

These resources provide health systems, local governments, and Emergency Management Agencies data analytic resources to help stem the tide of Coronavirus. As another benefit, by chaining together implementations of OGC standards (such as WMS, WFS, WPS, SOS, SensorThings API or OGC API - Features etc), scalable visualization of case counts, disease progression, and health resources can be displayed ensuring all users have the same view of the current state of the pandemic – this enables collaboration across the globe enabling coordinated response.

Chapter 5. Data Considerations and Related Recommendations

5.1. The Role of an SDI

A Health SDI can be leveraged to address challenges in healthcare today, such as the issuing of reports surrounding the maternal mortality rate. An ideal approach to rectify the problem can be to develop a spatial data infrastructure that enables health data to be exchanged in Geography Markup Language (GML) in order to standardize the semantics and definitions of data being captured and reported. This will facilitate both integration of data from different sources and comparison of results reported from different health systems and nations.

A spatial data infrastructure will also allow the health data to be easily mapped – and layered against social determinants of health, including but not limited to population density, education, income, transportation, environmental factors, climate change, and a variety of other factors. In addition, an SDI will enable the inclusion of new data sources that currently aren't considered when analyzing health outcomes, such as environmental sensors, smart city sensors, and satellite data. This will allow more data and more diverse data to be brought to bear on health data analytics that was previously possible – leading to more comprehensive research into and discovery of both the root causes and solutions to adverse outcomes that plague our global community.

5.2. Conceptual model recommendations

The INSPIRE report A Conceptual Model for Developing Interoperability Specifications in Spatial Data Infrastructures, especially on pages 40, 46, and 52 of the report provides important mode recommendations for services, data and data harmonization:

- **Download Service Strategies** - To make data available through a download service, data is typically transformed offline to create a static view that is compliant with the interoperability target specification and respecting privacy laws. Alternatively, data can be transformed inside the download service 'on-the-fly', according to previously defined mapping rules. A third option is to use a separate transformation service that executes predefined or user-defined mapping. It should be the responsibility of each data provider to choose the method and enable the necessary data transformation according to this choice.
- **Harmonized Schema and Use Cases** - Pursuing the principle that the SDI should bring together existing data, requirements from use case scenarios should be compared with existing 'as-is' data availability. This analysis can reveal whether the requested data can be supplied by the data providers. If so, it also shows the complexity of the related transformation work. If there is no one-to-one relationship between the proposed harmonized schema and the theme-related datasets, data integration might be still required at the level of the data sources or by the users. An example of a harmonized model is shown in Figure 1 of this White Paper.
- **Controlled Vocabularies** - Health data systems should put efforts on using common controlled vocabularies. Control vocabularies might be required for treatment names and codes, environmental conditions, etc. Existing controlled vocabularies are:

- UMLS
- SNOMED-CT
- MeSH
- HL7

5.3. Functional areas recommendations

Building a framework requires to partition the data needs in functional requirements. The suggested functional areas are as follows:

- data collection
- data access
- data processing
- data publication and sharing
- data visualization and decision support
- data privacy and protection
- data discovery
- semantic rich metadata
- data from sensors

5.4. Data recommendations

- **Data Security** - Data stored whether locally or in a cloud environment needs to be highly secure (critical applications) and comply with legal constraints.
- **Data Anonymization** - Aggregated data needs to be anonymized at an appropriate level, considering national regulations on aggregation of health data at given scales. The International Organization for Standardization (ISO) provides ISO 25237:2017(en)Health informatics — Pseudonymization as a potential method for privacy protection of personal health information of data within national borders as well as for transnational communication [12].
  - **De-Identification** - In the context of U.S. Federal health care regulation, the Health Insurance Portability and Accountability Act (HIPAA) provides guidance on methods for de-identification of protected health information (PHI). Protection is also afforded to patients receiving treatment for substance abuse and mental health disorders. The General Data Protection Regulation (EU) 2016/679 (GDPR) is a regulation in EU law on data protection and privacy for all individual citizens of the European Union (EU) and the European Economic Area (EEA). It also addresses the transfer of personal data outside the EU and EEA areas.
  - **Data Suppression** - Data is suppressed and omitted from data analytics and visualization when N<10, e.g., when there are less than 10 patients in a ZIP code. At times, data is suppressed when N<11, in other words, an N of 10 is also suppressed. This is to ensure de-identified data cannot be easily re-identified.
- Data Harvesting – By following OGC open data standards, an SDI enables the harvesting of data

sets that are stored in different locations. This expands the accessibility and availability of data without duplicating the overhead associated with data storage and management.

- Data Analysis – Numerous tools can be made available through and housed on an SDI for the purposes of analyzing data to provide decision support and predictive capabilities – as well as pre-processing the data. This can be as simple as a filter (such as to visualize ony those postal codes where the population exceeds 10,000 individuals) and as complex as machine learning-based artificial intelligence (AI) algorithms (such as a regression analysis to predict future adverse health events, such as a maternal mortality).

5.5. Data Requirements

For the data requirements the following types of data are assumed:

- Vector data: Data that can be represented as points, lines or polygons. Tabular data can be represented in vector format if there is a column that provides the geospatial coordinates.
- Coverage data: Usually gridded data including raster and model outputs that has a grid as a reference.
- Sensor data: Data is more dynamic in nature than vector and coverages, usually a time series of a sensor in particular location Formats and Standards include:

CSV

Encoding to represent data in a tabular format, separated by a comma.

CSW

The OGC Catalog Services for the Web provides a web interface to discover, get and update geospatial resources, including data and services.

ESRI Shapefile

Esri vector data format for storing information about geographic features.

GeoJSON

This is an encoding standard, by the Internet Engineering Task Force (IETF), for vector data written in JSON.

GeoPackage

An open, standards-based, platform-independent, portable, self-describing, compact format for storing vector features, imagery and raster maps in an SQLite database.

GeoSPARQL

OGC standard for representing and querying geospatial data on the Semantic Web. It extends SPARQL to allow querying of geospatial data and provides the language to represent geospatial data in RDF.

GML

The OGC Geography Markup Language, based on XML, is used to represent and share geospatial features. It also provides the means to define conceptual models (i.e. features types).

GTFS

Encoding for sharing transit data. It is composed of a set of CSV files grouped together under a zip file.

HL7 SDMX-HD

HL7 SDMX-HD (Health Domain) is a WHO implementation of the ISO's more general purpose Statistical Data and Metadata eXchange (SDMX) standard, and allows medical facilities to share and exchange medical indicators and metadata between medical organizations.

ISO 19115-1 and 19115-3

Geographic information — Metadata Model and XML Schema (replacements for ISO 19115:2003 and ISO 19139)

ISO 19117

Geographic information — Portrayal. Specifies a conceptual schema for describing symbols, portrayal functions that map geospatial features to symbols, and the collection of symbols and portrayal functions into portrayal catalogs.

KML

OGC standard, formally known as Key Hole Markup Language, is an XML language for expressing geographic annotation and visualization for two-dimensional and three-dimensional representations of the Earth.

O&M

The OGC Observations and Measurements defines a conceptual schema for encoding observations.

OASIS EDXL HAVE

OASIS EDXL HAVE The OASIS Committee Specification Emergency Data Exchange Language (EDXL) Hospital Availability Exchange (HAVE), released in January 2019, is an XML messaging standard primarily for exchange of information related to health facilities in the context of emergency management. HAVE supports sharing information about facility services, bed counts, operations, capacities, and resource needs so first responders, emergency managers, coordinating organizations, hospitals, care facilities, and the health community can provide each other with a coherent view of the health system.

OGC API - Features

This OGC standard provides Application Programming Interface (API) building blocks to create, modify and query features on the Web.

OGC SensorThings API

This OGC standard provides an open, geospatial-enabled and unified way to interconnect the Internet of Things (IoT) devices, data, and applications over the Web.

OSM

Open Street Map data format encoded in XML. The model is composed of nodes, ways, and relations. Usually, the file ends with .osm. If compressed then the file will end with .bz2 or .pbf.

OWL

The W3C Web Ontology Language is a standard for encoding ontologies or rich conceptual models. It is built on the RDF model.

RDF / SKOS

The W3C Resource Description Framework (RDF) provides a language to encode ontologies (rich conceptual models) or simple controlled vocabularies (e.g. multilingual gazetteers.)

SLD

The OGC Styled Layer Descriptor is a standard that enables an application to configure in an XML document how to properly portray layers and legends in a WMS. It uses the OGC Symbology Encoding (SE) standard to specify styling of features and coverages.

SOS

The OGC Sensor Observation Service provides a web interface to query sensor systems and data from sensors.

SPARQL

W3C recommended language to query RDF resources.

WCS

The OGC Web Coverage Service provides a web interface for querying coverages (i.e. digital geospatial information that varies in space and time).

WFS

The OGC Web Feature Service provides a web interface for querying and updating geographical features (i.e. vector data).

WMS

The OGC Web Map Service Interface Standard provides a web interface for requesting map images over the web.

WPS

The OGC Web Processing Service provides a web interface to run processes (e.g. classification, buffer, clipping, and geocoding).

The following table provides information about the data, its type and application area.

Table 3. Data requirements

Name	Description	Type	Application Areas	Standards
Population Data	Population Demographic Data, Global Indicators	Vector	Climate Health, Public Health, Sociology	CSV, WFS, GML, OGC API - Features

Name	Description	Type	Application Areas	Standards
Socio-Economic Statistics	Socio-economic data, e.g., income, education, etc	Vector	Climate Health, Public Health, Sociology	CSV, WFS, GML, OGC API - Features
Healthcare Cost Data	Data on costs of medical encounters, Claims data	Vector	Public Health	CSV, WFS, OGC API - Features
Healthcare Outcomes Data	Survey data	Vector	Public Health	CSV, WFS, OGC API - Features
Hospital Discharge Data	Medical records data	Vector	Public Health	CSV
Social Vulnerability Indices	Social Determinants of Health	Vector	Public Health, Disaster Recovery	CSV, WFS, OGC API - Features
Weather	Predictive Models	Coverage	Climatology, Disaster Recovery	CSV, WFS, GML, WMS, OGC API - Features
Climate Data	Predictive Models	Vector	Public Health, Disaster Recovery, Climate Health	CSV, WFS, GML, WMS, OGC API - Features
Disaster Loss Data	Data on the impact of natural and man-made disasters	Vector	Public Health, Disaster Recovery	WCS
Remotely Sensed Data	Aerial Imagery Analysis	Coverage	Climatology, Disaster Recovery, Public Health	WFS, WMS, WCS, OGC API - Features
Sensor Data	IoT, IoMT, Smart City Sensors	Vector	Public Health	OGC SensorThings API

Chapter 6. Health SDI Architecture Framework

A generic data workflow for a Health SDI is shown in Figure 6 below which is aligned with the architectural approach presented in The SDI Cookbook, developed with the support of the Global Spatial Data Infrastructure community. Alternate workflows and architectures are certainly possible to accomplish specific goals.

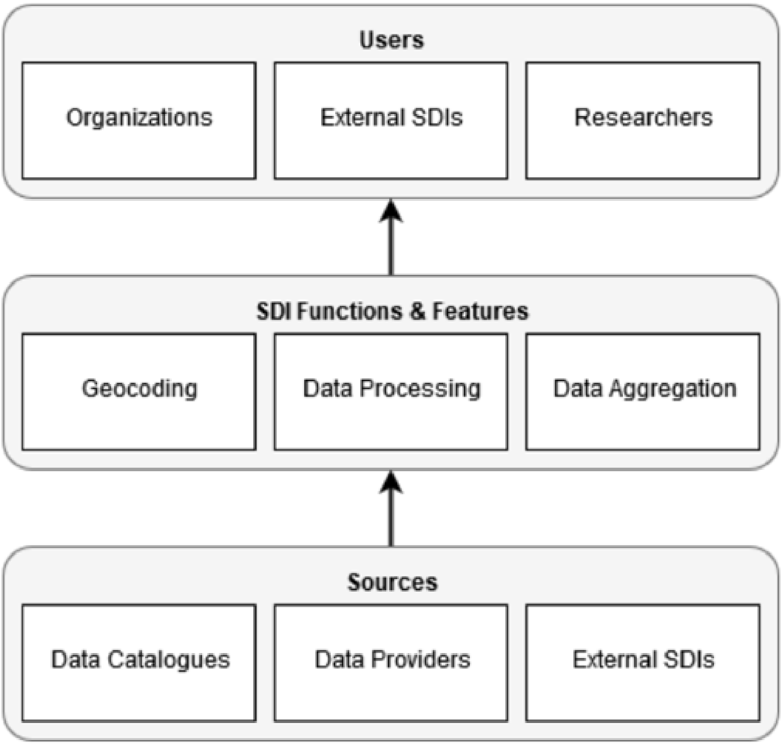

Figure 6. Simple Health Architecture.

The first step in building an SDI is to identify providers and sources of relevant data. U.S. health datasets can be retrieved from organizations including the Centers for Disease Control and Prevention (CDC), Centers for Medicare and Medicaid Services (CMS), and the Department of Health and Human Services (HHS). U.S. social datasets can be retrieved from the Census Bureau (Census) and Bureau of Labor and Statistics (BLS) among others. Global datasets can be accessed from the United Nations (U.N.); the World Health Organization (WHO) and its regional organizations, such as the Pan American Health Organization (PAHO); from national level health departments and data portals, such as the Bayanat.ae data portal of the United Arab Emirates, and a host of others. Similar resources at state and provincial levels, as well as health regions, also exist. Additional sources of data include health Registries, disease-specific healthcare industry organizations and affinity-groups, university and research organizations as well as other public and private organizations that make data available for public consumption.

Geocoding, processing, and aggregating the curated and harvested data results in a catalog, or an SDI, with a theme of health. This centralized catalog of health and non-health data that is relevant to health outcomes is valuable in and of itself. It provides an invaluable resource into population health status as well as aids research into the causes of and potential remedies for health challenges facing populations.

A Health SDI can provide tremendous additional value by supporting applications leveraging the data and geospatial tech to address specific challenges. An overall workflow for supporting and hosting such applications is shown in Figure 7 below.

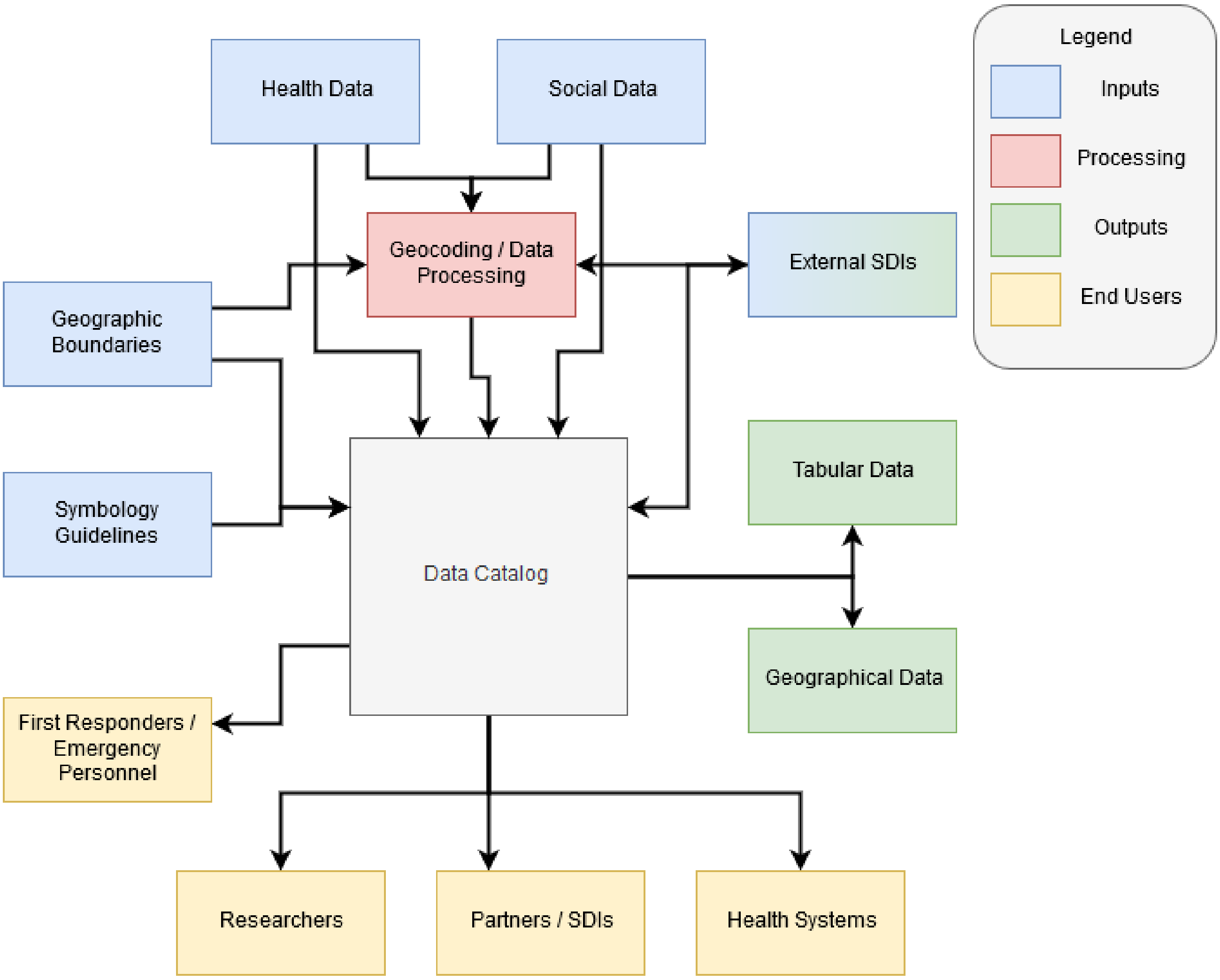

Figure 7. Generalized Health SDI Architecture.

Data from the Health SDI can be retrieved, in tabular or geographical data formats (when available), can be geocoded (when and as necessary), and prepared for analysis. Analysis of the data can include leveraging analytical tools, including commercial tools such as Tableau, or opensource tools such as R and Python. Applications based on artificial intelligence machine learning algorithms such as regression, K-Nearest Neighbors, and decision trees can be utilized to perform in depth and complex analyses of geohealth data. Additionally, spatial statistics such as spatial autocorrelation through Moran's Spatial K-Nearest Neighbor analyses provides information on the clustering and spatial dispersion of observations.

Symbology guidelines for specific outputs can be addressed and the analyzed data or layer can be published to the Health SDI. Finally, resources on the Health SDI can be made available to users in numerous ways, potentially including but not limited to:

- Linking to a data provider
- Direct download
- Through OGC Open Standards including WFS, WMS, SOS, SensorThings API and OGC API -

Features

Access can be open to the public or to private audiences through a username/password approach or through a variety of alternate security measures.

One value of an SDI, especially one utilizing Open Standards, is its ability to link to other SDIs, who themselves are engaged in aggregating, harvesting, and collecting data. This is especially valuable in the health field given concerns over the privacy and confidentiality of medical records. An institution with the medical records, such as a hospital, a health system, or an insurance company, can connect to a national or global Health SDI to leverage the population level data sets, to inform its research and data analytics without exposing personal medical records.

Popular SDIs with catalogs including wide sets of data include GeoPlatform.gov and AmeriGEOSS. NextGEOSS is one of the European Union's contributions to the Global Earth Observation System of Systems (GEOSS). This ability to connect to existing SDIs provides immediate access to large and diverse sets of data. So, it isn't necessary to do a lot of building to establish an expansive SDI - under the caveat that you build following open standards.

6.1. Future Work

This document advocates for the development of Global Health Spatial Data Infrastructure, discussing specific applications where such a solution can be helpful. In the process, the current market requirements as well as several use cases are also identified. Also discussed are additional challenges that are likely to be encountered in the process of establishing a Health SDI that can serve the world. Future work towards this end can involve:

- Reviewing and expanding on the initiatives included in Chapter 2
- Identifying new use cases for a Health SDI for inclusion in Chapter 3
- Updating of the data considerations in Chapter 4

Use cases of a Health SDI are expected to grow. For instance, disruptions in the supply chain of medical resources has been identified as a key challenge in pandemic response. A Health SDI can be leveraged to track – as well as potentially anticipate such disruptions in advance so contingencies can be planned.

In addition, a key next step can be the identification of the open data standards that either need to be updated to accommodate and support a Health SDI or the creation of a documented profile to guide the implementation of a Health SDI. The OGC's concept development studies, pilots, and testbeds are effective mechanisms to accomplishing these tasks and identify additional potential obstacles and solutions towards the construction of Health SDI.

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Annex A: Appendix A Lancet Countdown Indicators

Indicators Established in 2017:

```
Section 1: Climate change impacts, exposures, and vulnerability
1.1. Health effects of temperature change
1.2. Health effects of heatwaves
1.3. Change in labour capacity
1.4. Lethality of weather-related disasters
1.5. Global health trends in climate-sensitive diseases
1.6. Climate-sensitive infectious diseases
1.7. Food security and undernutrition
1.7.1. Vulnerability to undernutrition
1.7.2. Marine primary productivity
1.8. Migration and population displacement

Section 2: Adaptation planning and resilience for health
2.1. National adaptation plans for health
2.2. City-level climate change risk assessments
2.3. Detection and early warning of, preparedness for, and response to health
emergencies
2.4. Climate information services for health
2.5. National assessment of vulnerability, impacts, and adaptation for health
2.6. Climate-resilient health infrastructure

Section 3: Mitigation actions and health co-benefits
3.1. Carbon intensity of the energy system
3.2. Coal phase-out
3.3. Zero-carbon emission electricity
3.4. Access to clean energy
3.5. Exposure to ambient air pollution
3.5.1. Exposure to air pollution in cities
3.5.2. Sectoral contributions to air pollution
3.5.3. Premature mortality from ambient air pollution by sector
3.6. Clean fuel use for transport
3.7. Sustainable travel infrastructure and uptake
3.8. Ruminant meat for human consumption
3.9. Health-care sector emissions

Section 4: Economics and finance
4.1. Investments in zero-carbon energy and energy efficiency
4.2. Investment in coal capacity
4.3. Funds divested from fossil fuels
4.4. Economic losses due to climate-related extreme events
4.5. Employment in low-carbon and high-carbon industries
4.6. Fossil fuel subsidies
4.7. Coverage and strength of carbon pricing
4.8. Use of carbon pricing revenues
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4.9. Spending on adaptation for health and health-related activities
4.10. Health adaptation funding from global climate financing mechanisms

Section 5: Public and political engagement
5.1. Media coverage of health and climate change
5.1.1. Global newspaper reporting on health and climate change
5.1.2. In-depth analysis of newspaper coverage on health and climate change
5.2. Health and climate change in scientific journals
5.3. Health and climate change in the United Nations General Assembly
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Indicators Established in 2018:

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Climate change impacts, exposures, and vulnerability
 Indicator 1.1: vulnerability to the heat-related risks of climate change
 Indicator 1.2: health effects of temperature change
 Indicator 1.3: health effects of heatwaves
 Indicator 1.4: change in labour capacity
 Indicator 1.5: health effects of extremes of precipitation (flood and drought)
 Indicator 1.6: lethality of weather-related disasters
 Indicator 1.7: global health trends in climate-sensitive diseases
 Indicator 1.8: climate-sensitive infectious diseases
 Indicator 1.9: food security and undernutrition
 Indicator 1.9.1: terrestrial food security and undernutrition
 Indicator 1.9.2: marine food security and undernutrition
 Indicator 1.10: migration and population displacement

Adaptation, planning, and resilience for health
 Indicator 2.1: national adaptation plans for health
 Indicator 2.2: city-level climate change risk assessments
 Indicator 2.3: detection, preparedness, and response to health emergencies
 Indicator 2.4: climate change adaptation to vulnerabilities from mosquito-borne
diseases
 Indicator 2.5: climate information services for health
 Indicator 2.6: national assessments of climate change impacts, vulnerability, and
adaptation for health
 Indicator 2.7: spending on adaptation for health and health-related activities
 Indicator 2.8: health adaptation funding from global climate financing mechanisms

Mitigation actions and health co-benefits
 Indicator 3.1: carbon intensity of the energy system
 Indicator 3.2: coal phase-out
 Indicator 3.3: zero-carbon emission electricity
 Indicator 3.4: access to clean energy
 Indicator 3.5: exposure to ambient air pollution
 Indicator 3.5.1: exposure to air pollution in cities
 Indicator 3.5.2: premature mortality from ambient air pollution by sector
 Indicator 3.6: clean fuel use for transport
 Indicator 3.7: sustainable travel infrastructure and uptake
 Indicator 3.8: ruminant meat for human consumption
 Indicator 3.9: health-care sector emissions
```

Finance and economics

- Indicator 4.1: economic losses due to climate-related extreme events
- Indicator 4.2: investments in zero-carbon energy and energy efficiency
- Indicator 4.3: investment in new coal capacity
- Indicator 4.4: employment in renewable and fossil-fuel energy industries
- Indicator 4.5: funds divested from fossil fuels
- Indicator 4.6: fossil fuel subsidies
- Indicator 4.7: coverage and strength of carbon pricing
- Indicator 4.8: use of carbon pricing revenues

Public and political engagement

- Indicator 5.1: media coverage of health and climate change
- Indicator 5.2: coverage of health and climate change in scientific journals
- Indicator 5.3: engagement in health and climate change in the UN General Assembly
- Indicator 5.4: engagement in health and climate change in the corporate sector

Annex B: Revision History

Date	Editor	Release	Primary clauses modified	Descriptions
April, 2017	Eddie Oldfield	.1	all	initial version
May 12 2017	Luis Bermudez	.2	all	formatted in Asciidoc, overall edits and restructuring
June 7, 2017	Scott Serich	.3.0	all	Performed overall general checking to prepare for issue resolutions
June 8, 2017	Scott Serich	.3.1	all	Resolve GitHub Issue #1
June 8, 2017	Scott Serich	.3.2	all	Resolve GitHub Issue #2
June 8, 2017	Scott Serich	.3.3	all	Resolve GitHub Issue #3
June 9, 2017	Scott Serich	.3.4	all	Resolve GitHub Issue #4
June 9, 2017	Scott Serich	.3.5	all	Resolve GitHub Issue #5
June 9, 2017	Scott Serich	.3.6	all	Resolve GitHub Issue #6
June 9, 2017	Scott Serich	.3.7	all	Resolve GitHub Issue #7
June 9, 2017	Scott Serich	.3.8	all	Resolve GitHub Issue #8
June 9, 2017	Scott Serich	.3.9	all	Resolve GitHub Issue #9
June 9, 2017	Scott Serich	.3.10	all	Resolve GitHub Issue #10
June 9, 2017	Scott Serich	.3.11	all	Resolve GitHub Issue #11
October 31, 2019	Ajay Gupta	.4	all	Final edits for TC approval
March 27, 2020	Ajay Gupta	.4.1	all	Final edits

Date	Editor	Release	Primary clauses modified	Descriptions
March 30, 2020	Gobe Hobona	.4.2	all	Final edits prior to publication

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