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Conflating Boundaries to Envision Urban Public Health

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ABSTRACT This article explores the important role of visual and spatial analysis in addressing Urban Public Health needs. It focuses particularly on the need for a multidimensional approach that incorporates design, visualization, and aesthetics to create evidence-based arguments. It also explores the role of technologies, such as geographic information systems (GIS), in visualizing epidemiological data and the important findings that may be extrapolated. It first addresses the multifaceted and changing nature of public health—particularly the growing influence of environmental and social determinants of health and their impact on human well-being and development. It discusses the history of mapping/visualization/spatial analysis for public health, beginning with John Snow. It concludes with an optimistic outlook of the potential for applying visual analysis and technologies to overcome gaps in public health, providing research insights into more effectively addressing the basic needs of people in both the developing and developed world.

> *If cities are the "defining artifacts of civilization" a nation may now be judged by the health of its urban majority.*
>
> —*Christopher Dye*[1]

We live in a rapidly changing, more-connected and increasingly urban world: over 50% of the global population now resides in cities.[2] Growing urban concentrations are being driven by population growth and migration to bustling metropolitan habitats in the developing world, such as China, India, and several Latin American countries.[3] Advanced technologies and lower costs to access information, communication, and transportation have increased the flow of knowledge and people. This enhanced connectivity has highlighted disparities in the health, quality of life, and well-being of city inhabitants across the world. It is in this context of global and urban complexity that the need arises for multidimensional research, analysis, and the tackling of urban public health issues.

Urban public health can benefit from visual and spatial analysis, which can address knowledge gaps in global urban public health research and services; build an evidence base to advocate for policy change; and strengthen health systems and education. This article demonstrates how visual and spatial analysis can help overcome knowledge/information lapses and hence improve urban public health worldwide. The intention behind it is to conflate traditional disciplinary boundaries and expertise and bring together ideas on a shared platform that addresses urban complexity, while targeting public health and human well-being through information, design, and technology. Faced with the global economic slowdown, a public health and sanitation crises, compounded by exploding urban populations and growing 'slums,' it is timely to traverse traditional disciplinary boundaries, distinctions, and dichotomies in order to clarify, contextualize, and overcome challenges to urban public health. Cholera outbreaks in 2008 and a looming H1N1 Swine flu pandemic in 2009 demonstrate the urgent need to leverage resources for a more effective multifaceted and multi-sector response to urban public health concerns.

URBAN PUBLIC HEALTH

Public health is defined by the Association of Schools of Public Health as: "the science of protecting and improving the health of communities through education, promotion of healthy lifestyles and research for disease and injury prevention."[4] It entails educating local communities and influencing behavior change, encompassed in provision of health systems, services and access to tools and resources that prevent epidemics and promote well-being.[5] Twentieth century achievements include improved quality of life, evidenced by longer lives and reduced infant and child mortality rates, particularly in the developed world.[6] Increasingly interdisciplinary, varied and dynamic, it encompasses several academic disciplines while seeking a multi-sector focus on population health and well-being.[7] It differs in its preventative (versus curative) approach to health: "in the traditional clinical setting, the focus is on a single patient; in the public health setting the focus is on the population."[8] In the urban context, however, individual behaviors and population health are vitally linked.

> **ur·ban (n):** "of, relating to, characteristic of, or constituting a city."[9]

> **pub·lic health (n):** "the art and science of dealing with the protection and improvement of community health by organized community effort and including preventative medicine and sanitary and social science."[10]

Urban public health entails protecting, promoting, and improving the health of urban communities. It links science with social science research and constitutes a growing area of interest for individuals, academic institutions, governments, civil society, and corporations. It is an interdisciplinary field that straddles the intersection of urban policy, design, and planning in order to improve the well-being of urban populations. It encompasses educating and informing populations about: nutrition and disease as well as surveying, researching, and protecting public exposure to diseases and illnesses, environmental health risks and hazards, toxicity, air-pollution, and other social determinants. Distinct from traditional public health because of its "urban" dimension, it highlights how community health is subject to specific, urban factors. Inherently interdisciplinary and spatially and geographically specific, urban public health stands to benefit from multidimensional research and analysis.

Urban Public Health is multifaceted, complex, and encompasses numerous factors and indicators, from mortality and longevity, to ratios of green spaces, environmental toxicity, and freedom from pollution: to access to fresh and local foods. Understanding urban development and public health problems associated with it is complex because of the many interconnected and overlapping variables that affect community well-being. This poses a challenge to public health experts, researchers, and practitioners. However, visualization of data and geo-spatial analysis of disease transmission routes and environmental and social health determinants can help public health workers and urban planners clarify and better understand complex information. It also makes health information more communicable to urban populations, who in order to attain optimum urban public health, need to be informed and educated about urban public health issues and their solutions, such as: the prevention of disease, improvement of living environments, nutrition, etc. It is in this area that designers, planners, and those in the field of aesthetics need to be more involved.

Urban public health links population health with individual behavior and knowledge, because issues of well-being and personal hygiene inevitably boil down to the behavioral choices of an individual—whether as informed decisions about food, condom use, basic sanitation and hygiene, or applying knowledge and information for flu and infectious disease protection. These are also affected by urban systems and infrastructures that might facilitate disease transmission—sanitation and sewage systems, waste management, urban water infrastructure, air pollution, etc. They all rely on effective resource allocation, infrastructure, surveillance, robust health services and systems, as well as publicly available information and educational materials. Urban public health policy influences a community's health in multiple ways, including through policy implementation and advocacy, by communicating health related information and education, strengthening health systems and services, as well as through sensitive urban planning and infrastructure management in sectors such as water, sanitation etc.

Visual and spatial research and analysis can direct and inform urban public health needs and development agendas in cities across the world. It can powerfully engage and communicate health information to populations. It can also educate communities and individuals while gathering information, as well as strengthen geographically specific health services and access via spatial analysis and enhance surveillance systems. It can employ data visualization to clarify and reveal latent factors affecting health at the intersections of urban planning, space (population density) and well-being. This is essential to facilitate evidence-based policy and plan healthier urban environments. It is also crucial in order to educate populations, inform them of local forms of knowledge, and ensure that urban health policy and planning addresses the needs of present and future generations.

THE CHANGING NATURE OF PUBLIC HEALTH

Conflating disciplinary boundaries provides insights to improve urban public health—linking individual and population health in urban spaces, while considering unique urban processes and the challenges of traditional and complex urban and health issues. While it remains rooted in the western medical knowledge tradition focused on sanitation and hygiene, the field of public health is evolving in response to diverse urban needs. It is increasingly informed by the social sciences, particularly the social and environmental determinants of human health, besides a growing "urban" dimension.

Bridging the ideas of population and individual human health, the definition of urban public health overcomes or bridges a policy and academic divide. Factors affecting urban public health include planning and infrastructure, such as sidewalks for exercise or sewage systems, which facilitates incorporating a need for the role

of planning, urban/municipal policy, health systems, and services provisions while
emphasizes a need to bridge individual, and
community health in their spatial context. Individual behaviors ultimately inform public health of the community.

The multiple dimensions of urban health are a growing focus of academic research, particularly from community health and planning perspectives. At Johns Hopkins University's Institute of Urban Public Health, researchers explore various knowledge streams to prevent disease and address urban health issues.[11] Researchers at Columbia University's Mailman School of Public Health explore the environmental and socio-economic determinants of health.[12] It's "Urbanism and the Built Environment" program explore the relationship between the built environment and public health; but this analysis is limited to "formal" or built aspects of cities.[13] This issue of physical infrastructure as a determinant of health is becoming increasingly visible in the developing world, where informal settlements in urban areas lack basic shelter, clean water access and sanitation amenities.

Architects collaborate with schools of dentistry, public health, and history departments at Columbia University, leveraging digital modeling and mapping tools to re-think "one of the oldest ambitions of good design."[14] The "Built Environment and Health" is an interdisciplinary research project led by an epidemiologist that uses spatial data to explore the implications of land use, public transit and housing on physical activity, diet, obesity.[15] This informs urban public policy to promote better health in the New York City and greater metropolitan areas.[16] Similarly, Harvard University's School of Public Health explores the role of geographic information systems (GIS) for geospatial public health research.[17] These examples show that new ways of thinking about public health and promoting healthy urban populations are taking shape. There is awareness amongst academics to deepen and broaden the notion of public health as it relates to urban spaces and processes, given the importance of contextualizing, understanding, and monitoring the health of diverse urban populations.

Differences amongst and within cities pose several research and analytical challenges. Urban spaces are evolving, but have also been associated with the evolution of ideas of public health and practice.[18] The physical cities themselves increasingly contribute to ecological pressures, impacting the biosphere via greenhouse gas emissions and heat inefficient buildings, which affect climate change.[19] Climate change and green energy policy are set to pose a growing urban public health concern. This is crucial because, "until the second quarter of the 20th century, the dominant cause of mortality among industrialized urban populations was infectious diseases."[20] With intense industrialization in the absence of air quality controls, pollution levels increased in developed world cities, as they have in developing world cities.[21]

Urban public health issues in developing countries, however, face added challenges. Laurie Garrett notes that, "like their American and European counterparts in the late 19th century, India's intellectuals in 1994 cried out for sanitation and hygiene, the absence of which they blamed not only for the plague, but also for every imaginable failure in their society."[22] This reality is striking, particularly given the relationships between socioeconomics and space: "The chances of being rich and getting plague, in India or anywhere else in the world, are about as remote as the ability of the rat flea to jump from its slum habitat to the distant electronically protected environment of the rich."[23] Spatial segregation in urban areas is often related to income for instance, with securitized and gated communities arising in urban metropolitan areas. Garret concludes that: "No new technology is required to prevent plague and cholera in the developing world—it just requires the implementation of basic public health measures."[24] Policy and its implementation can be affected by advocacy that is informed—and created—by visual and spatial research. Furthermore, education and health communication challenge preconceived notions and educate in "hygiene" and sanitation, affecting behavior change—a core part of public health.

The dimensions of public health that need to be addressed are increasingly multifaceted, urban, and associated with local forms of knowledge. The coupling of water and sanitation, which has proved problematic in the developing world, is now being raised as part of a multi-disciplinary understanding of health, with social science perspectives being added to the western medically rooted idea of public health. Environmental health, which incorporates facets of geography, ecology, planning, and construction, as well as policy measures to control air pollution and monitor air quality—is now increasingly emphasized. Similarly, social determinants of health such as income and poverty are also being recognized. The changing nature of public health is beginning to explore not only relationships between the 'built environment' and health, but also the impact of urban living on individual health and well-being, with a focus on environmental health and social determinants. This shift seems to be in response to growing challenges in the developing world, and overcomes a severe limitation of associating public

health with constructed, formal environments. By looking at and beyond relationships between health and the built environment, research is uncovering lapses in knowledge about the informal and un-built communities. Visual and spatial research can highlight this missing dimension of envisioning urban populations and their vulnerabilities.

Amartya Sen notes: "we seek good health not only because it makes our lives more pleasant and less painful… but also because having a long and healthy life enhances our capability to do what we would like to achieve."[25] He highlights the continued burden of traditional diseases, noting that the current global public health crisis stems from a combination of new pandemics such as HIV/AIDS, and traditional illnesses, such as malaria, tuberculosis and gastrointestinal diseases, which are given less donor importance: "The case for cleaner water, better sanitation, and the elimination of parasites has never been stronger," and can benefit from new perspectives and analyses.[26]

A range of policies, systems and actions influence health and must be considered when evaluating the use of resources in the pursuit of urban public health.[27] Urban public health and policy-making must explore local (urban) environmental as well as economic and social arrangements that may have important influences on individual and community health.[28] Sen highlights the 'negative' effect of poverty and inequality on health; socially and economically vulnerable groups "suffer disproportionately from bad health and premature mortality, linked particularly with behavioral adaptation—such as excessive drinking, smoking, and lack of exercise—that reflect their frustration and which, at the same time, badly affect their health... An epistemic approach to health care has to cast the net quite wide to have an adequate grip on the causal influences that impact on illness and mortality."[29] Thus, urban public health requirements dictate a need for locally informed health knowledge that can visualize and address these dimensions.

URBAN LIVING AND THE EFFECTS OF URBANIZATION

ur·ban·i·za·tion(v): "the process of becoming urbanized"

ur·ban·ize (v): "to cause to take on urban characteristics; to impart an urban way of life"

Urban spaces in the developing world are often densely populated and include formal and informal aspects; the latter defined by a lack of or poor infrastructure such as housing, water or sewage systems, and health services etc. Spatial analysis of urban infrastructure provides insights into a host of environmental and social factors affecting health, which include access to clean water, formal housing, green spaces, numbers of health clinics, access to services, and socio-economic indicators, such as income—all of which impact the quality of urban life.

Urbanization and the flows of people into cities have added to the diverse public health challenges.[30] Urbanization is associated with falling birth and death rates and a shift in burden of illness from acute childhood infections to chronic, non-communicable diseases of adults.[31] While individual and community health tends to improve with urbanization, the degree to which individuals benefit depends upon "the effectiveness of public services," and on public and private partnerships.[32] Benefits of urbanization are not uniform, and economic growth is also associated with increased health inequalities between and within countries and cities.[33] Although health tends to be better in urban areas, research has not yet shown that benefits of urban living outweigh its health risks.[34] For instance, the proportion of overweight individuals is rising faster in cities than in rural areas and poorer urban inhabitants are often exposed to greater environmental health hazards, including higher levels of indoor and outdoor air pollution.[35]

Urbanization drives the "global demographic transition" and shifts from high to low birth rates, short to long life spans.[36] It can also shape nutritional transitions, i.e. shifting burden of disease and illness from "acute childhood infections to chronic and mostly non-communicable diseases of adults."[37] Christopher Dye notes, "many of the prescriptions for better urban health are in fact self-evident and are often inexpensive: healthy housing, primary health care, communicable disease control though sanitation and vaccination, safe roads, and targeted assistance to women."[38] Can these needs be visibilized, visualized and addressed through participatory visual research and analysis?

Urban public health research and analysis can be strengthened by targeting gaps in education, services and infrastructure relating to urban well-being. Looking at urban public health globally the difference between developed and developing world cities becomes striking. Furthermore, its relationships to visual and spatial analysis in terms of urban planning, infrastructure as well as the environmental and social determinants of health, becomes unavoidable.

The United Nations designated 2008 as the "International Year of Sanitation," recognizing access to sanitation as vital to "ensuring health, dignity and sustainable social and economic development," as well as a basic human right.[39] Yet, in December 2008, there was a massive

outbreak of cholera in Zimbabwe, compounded by inadequate access to safe drinking water and poor hygiene.[40] This is common in many countries where multi-sector, local (urban) public health systems remain poor or ineffective. Iraq and India witnessed smaller scale water-borne disease outbreaks, including cholera, in 2008. Epidemics like these are linked to limited access to clean water and sanitation, are too often endemic, and require a multidimensional response.

Interestingly, it was the fear of cholera epidemics in American and European cities that leveraged improvements there in urban sanitation, housing, health services and water supply.[41] Cholera has not returned to European cities in recent years, due systems to purify urban water supplies and prevent contamination by bacteria have been established.[42] Factors such as a lack of funds, policy prioritization and effective resource allocation continue to prevent the resolution of public health issues in developing world cities.[43] Visual and spatial research and analysis can highlight and begin to effectively address them.

In metropolitan slums, urban and peri-urban areas of India, dysentery and diarrhea, which are easily treated and preventable in most developed world cities, are leading causes of death among children of low socioeconomic status. They are associated with factors like poor sanitation, improper sewage systems, overcrowding, and limited access to clean water and medical services. Density is linked with disease transmission, incidence and prevalence. This raises the questions: Are resources and policies being effectively advocated, informed, and targeted? Can visual / spatial analysis in urban public health help better address these issues by examining infrastructure, informing planning, and visualizing epidemiological data?

LOCALLY INFORMED URBAN HEALTH KNOWLEDGE

> *In as much as certain cognitive tasks and principles are tied to nature's laws, these tasks and principles are different to language, culture, gender, or the particular mode of information that is provided.*
>
> *—Edward Tufte*

Even though all urban habitats do have shared public health problems, it is important to be culturally and site specific when looking at urban public health needs and solutions. The *favellas* of Rio, the *villas* of Buenos Aires, and the *slums* of Mumbai are different sets of unique circumstances that link issues housing, urban planning, and public health. Similarly, public health needs in New Orleans differ from those in London and are housed in different systems that affect change. This raises the issue of how locally or lay informed knowledge about health—including individual behavior, environmental and social determinants—can challenge so called "expert," widely accepted or scientific knowledge.

Local environmental health knowledge can inform the health of lower income, vulnerable communities facing disproportionate environmental and health risks, thereby reducing negative impacts.[44] Similarly, "non-scientific" or lay knowledge, particularly relating to urban environments and towards human and environmental health—can contribute data, effective (participatory) methods of analysis and highlight discrepancies between scientific method of inquiry and therefore public policy.[45] This is important for urban communities to prioritize and address their own health concerns.

There are points of convergence underlying the "urbanization, sanitation and health in 19th century industrialized nations and the developing world"—and the reasons why many countries, have not managed to re-address their urban sanitation and health problems.[46] Steven Johnson notes:

> *Dense cities are engines of economic growth and social tolerance; they raise life expectancies while lowering the childbirth rate. Mass transit-based cities like New York are among the most energy efficient large scale human settlements on the planet. Yet, cities also cultivate new problems and new threats—rogue viruses, terrorists, wealth inequality, etc. The mega cities of the developing world are living through the same deadly sanitation issues that the Victorians wrestled with, only they are trying to manage cities of 20 million people, not two million.*[47]

How can these traditional health burdens be addressed in the face of growing urban complexity?

Spatial analysis within urban spaces can show the poverty dimension to segregation and vulnerability. The "broken windows" theory, first put forth by George Keilling and Catherine Coles in 1996, has been applied to understand safety and urban health issues and now the transmission of STDs. It argues that impoverished neighborhood conditions indicated by broken windows affect residents' health by "inhibiting or facilitating risk-taking behavior, by influencing social relationships, and by exposing residents to visual cues that can arouse fear, anxiety, and depression." The theory supports that poorer people suffer disproportionately from communicable diseases, as well as higher

documented rates of obesity, injury, and asthma among children who live in poverty. However, this might also be due in part to access to public health facilities who share the data publicly. Nevertheless, while some health problems can be explained by urban lifestyle and environmental determinants, reasons why poorer people populations tend to have "unhealthier lifestyles" is of importance—is it the effect of their surrounding environment? Clearly, poverty as a determinant of health and well-being goes beyond just low income.[48] Spatial analysis of distinct urban communities within cities —divided by income, or in informal settlements—is becoming increasingly important. How can these issues be "put on the map"? Mapping in this case can visualize an help to address (i.e. break) cycles of spatial poverty and segregation within urban communities—by visualizing and making their issues and linkages to space more visible.

Meaningful urban development in urban areas requires targeted strategies that are evidence based and, "policies and actions, which emphasize local realities over and above global concerns and priorities."[49] In the same vein, systems of well-being that relate to space should look to locally and culturally specific knowledge—systems such as vastu or *feng shui* and traditional systems of well-being such as *Ayurveda* or *Acupuncture*. The link between tradition and modernity is important, as are links between multiple sources and overlapping forms of traditional, visual, and spatial knowledge.

Urban residents of developing "megacities," such as Mexico City, Sao Paolo and New Delhi, face "the worst of the traditional and modern worlds."[50] They face a range of negative public health influences—pollution, lack of sanitation, exposure to human excrement and unsafe drinking water, as well as exposure to "hazardous, synthetic organic chemicals" in air, food and water as well as their surroundings.[51] In the Yamuna River that runs through New Delhi, for instance, the coli form count "increases 3000 fold" and receives 20 million liters of industrial waste from the time it enters to the time it leaves the city.[52] The city's air quality is also among the worst in the world, and impacts the health of its inhabitants.[53] Large cities in low-income, developing countries face particularly complex physical and urban, environmental public health issues and vulnerabilities. Urban residents often risk diseases and injuries related to poor sanitation, unsafe drinking water, dangerous roads, polluted air, and indoor air pollution and toxic wastes.[54] How can public health interventions and monitoring be sensitive to urban spaces, whether developed or developing, be environmentally healthy, culturally specific and ultimately successful, particularly for the most vulnerable?

AN URBAN HISTORY: PLANNING AND MAPPING

Urban spaces are distinct and dynamic with unique environmental, social, and economic factors influencing space. Even within urban spaces, there is diversity of use, infrastructure, and population density. The use of space, its construction and aims, the density of populations in relation to infrastructure, services, and expenditure are pertinent but often invisible to research unless spatial analysis is employed. This highlights the need for geographic and spatial specificity to reveal the multiple dimensions required for urban health and planning.

> **spa·tial (adj):** "relating to, occupying, or having the character of space."[55]

Space is considered at all times by designers, architects, and urban planners. However, space—and geography—is an often overlooked dimension by researchers, development theorists, or policy makers. In thinking of the health of urban communities how can cities as sites of innovation and home to increasing populations become healthy and livable, while promoting the well-being of their constituents? This arguably can be addressed through mapping tools or geospatial analysis. Since the 19th century, cities in Europe have been associated with the evolution of ideas of public health, practice and space.[56] The links between public health and physical space are innumerable and fundamental for human development and well-being. Spatial thinking, in terms of research and analysis, is not new in public health and holds the potential to address urban health concerns.

Public health emerges from a western concept centered on hygiene, and in 19th century Industrial Europe, urban health and sanitation was primarily linked with solid waste, water and sanitary waste disposal.[57] A 2008 poll by the British Medical Journal voted England's "sanitary revolution" i.e. the introduction of "piped water" and the introduction of sewage systems to people's homes in the 19th century in Europe, as "the most important medical milestone since 1840," ahead of the discovery of antibiotics and the development of anesthesia.[58] Yet, an estimated 2.5 billion people—40% of the world's population—continue to lack access to basic sanitation and public hygiene amenities.[59]

Harvey notes that sanitation was not historically prioritized in the development of urban plans, especially when compared to water supply infrastructure.[60] It now needs to be addressed, "separately from water supply, at least in terms of policy, strategy and funding to ensure that it receives sufficient emphasis and prioritization."[61] This

troublesome "coupling of water and sanitation" is based on the need for water to supply water-borne sewage systems in industrialized nations.[62] Yet, the norm in many developing countries is "dry, on-site sanitation systems", with "no direct requirement of water other than for personal and domestic hygiene."[63] With increasing urbanization in the developing world, it is crucial to develop specific strategies for urban and peri-urban sanitation.[64] Moreover, sanitation and hygiene are largely rooted in western, medical concepts that can be problematic when 'imposed' on developing countries in non-specific or culturally insensitive way. This highlights the importance of participatory, community based mapping of infrastructures and spaces to see what exists—what lacks—and how they are all related to one another and inform the complexities of urban life. By visually representing and analyzing public health in relation to the unique space and geographic factors, mapping holds the potential to save lives.

SAVING LIVES: MAPPING FOR URBAN PUBLIC HEALTH

Inherently interdisciplinary, urban public health benefits from multidisciplinary research and a multidimensional approach, particularly one that emphasizes visual and spatial research and analysis. This holds the potential to add clarity and context to urban public health knowledge. The intersections of preventative measures to protect the health of communities in urban spaces, such as health education, urban policy and planning, and the need to support health services and systems through technology and public and private partnerships, evidence that visual and spatial analysis, can support and inform urban public health needs. This section explores the role of 'mapping' for public health.

For this article, the definition of mapping incorporates both the visual and (geo)spatial aspects of research and analysis. Maps are visual representations that provide complete, contextualized, or partial information. These images or representations are often to scale and represent spaces (planning maps showing infrastructure, density and constructed spaces for instance), statistics or data sets (information maps). The history of mapping or visual and spatial research and analysis for public health offer insights into the potential of addressing current and future needs and gaps in urban public health. Mapping thus links qualitative and quantitative research and analysis by allowing their contextualized and clarified visualization to overcome research and analysis challenges in urban public health.

> **map (n):** "a representation usually on a flat surface of the whole or a part of an area."[65]

> **map (v):** "something that represents with a clarity suggestive of a map."[66]

According to Edward Tufte: "Explanatory, journalistic and scientified images should nearly always be mapped, contextualized and placed on the universal grid. Mapped pictures combined representational images with scales, diagrams, overlays, numbers, words, images. Good mappings of realistic images have been produced throughout the long history of visual displays, but not often enough. Sensibly mapped pictures nearly always outperform purely pictorial representations for presenting, explaining and documenting evidence."[67] In Tufte's expert opinion, the visual representation of information—including display and analysis of statistics, quantitative data and qualitative information and evidence—is best conveyed while maintaining the importance of information design and aesthetics.

The relationship between maps, urban planning, and public health goes back to 19th century Europe. At that stage, sanitation was driving urban plans and infrastructural works and the links between public health and space were limited to sanitation and infrastructure. Maps have been used for urban planning and architecture construction purposes. The spread of cholera in Europe alerted people to the need to "invest in sanitation."[68] Fears of recurring cholera epidemics prompted city officials to create urban "health boards" in cities like London and New York, while strengthening infrastructure: expanding the networks of underground pipes to provide universal access to clean water and hygienic sewage disposal.[69] The fact that this problem has been recurring in 2008, signals a need to re-explore the power and potentials of mapping.

A HISTORY OF MAPPING FOR URBAN PUBLIC HEALTH

Epidemiological maps and the visualization of epidemiological data in its geographic context trace back to 19th century Europe. Dr. John Snow, an epidemiologist now regarded as the father of medical cartography, was responsible for the first documented example of visualizing epidemiological data. Snow's map of "cholera dots" was the first example of mapping epidemiological data ("epi maps"). Analyzing the explosive outbreak of cholera that struck London in 1854, each dot on Snow's map represented a cholera death in its spatial relation to a local water pump. Snow observed that cholera was spatially confined to those who lived near and drank from the Broad Street water pump. He had the handle of the contaminated pump removed, "ending the neighborhood epidemic which had taken more than 500 lives."[70] His visualization of data and mapping of cholera cases as

FIGURE 1: *Portion of the original John Snow Cholera Map from* CSISS.

"clusters" effectively ended London's cholera epidemic. By resorting to visualization, he was able to avert a crisis and save lives.[71]

Snow's visualization process employed a forensic approach, using cartography to uncover knowledge and reveal latent information via a series of organized observations that resulted in a simple visual. His map demonstrated that public health information can be more effective when simply and visually framed. The prevalent theory at the time held that cholera was spread by inhaling poisonous air. Snow's mapping of cholera-related deaths visually demonstrated that all deaths linked back to the broad street pump. It also evidenced the fact that cholera was in fact transmitted by contaminated water and urban water systems—and not through the air, as had been previously hypothesized.[72] By taking a data set and showing it in a simple visual and spatial context, Snow cartography provided a compelling, evidence-based argument.

Snow's discovery led to the building of London's sewer system in the next decade, an engineering achievement of the 19th century.[73] It also led to other urban public health reforms, which emphasized public health and hygiene. As a direct result of his work, when cholera recurred in London in 1866, city authorities focused on urging residents to drink only boiled water to combat the bacteria.[74] Since the completion of construction of its sewer, London has not had another cholera out break.[75] Other cities also built comparable infrastructure to ward off infectious diseases and maintain the health of the city.[76] With this came a shift from urban metropolitan areas waiting to "implode" to their being more "solid" and "sustainable."[77] Urban public health, particularly sanitation, is likely to be one of the most pressing challenge of the 21st century, given the increasing numbers of people moving to urban environments; the failure adequately explore the relationship between urban planning and public health may be a contributing factor.

The London cholera incident and its solution remind of the progress possible. Cholera is no longer a threat to metropolitan areas in the developed world, showing that comprehensive systems "providing public health services, waste management and clean water are critical to combat such issues."[78] However, this has yet to be effectively implemented in urban centers of the developing world.[79]

Snow's mapping is an example of the power of mapping and visualization as well as locally informed insights can challenge and inform prevailing or accepted knowledge. It also shows the importance of participatory mapping or visual research. This early instance of visualizing epidemiological "data" to inform urban public health needs effectively prevented a disease outbreak. The mapping demonstrated that incorporating locally informed knowledge and securing community participation can help overcome some lapses in traditionally medically rooted public health knowledge. Many of the disparities between the health of inhabitants in developing and developed world cities are partly based on a similar lack of or inaccurate information or "knowledge," resulting in ineffective systems, resource allocation and policy.

At an urban level, there are considerable differences in connectivity between the developed and developing world and the capacity of policy makers to leverage information and communication technologies to their advantage. Nevertheless, Snow's mapping example demonstrates that even simple and participatory two-dimensional cartography can assist in evidenced based advocacy in urban public health.

PARTICIPATORY AND INTERACTIVE MAPPING TECHNOLOGIES

The late 20th century underwent an information and communications revolution with the advent of major technological inventions, including personal computers and the internet. Information and communication technologies have resulted in "democratization of data"—individuals can now generate and transmit knowledge and information, including statistics. Advents in geospatial technology also offer opportunities

to strengthen urban public health. For instance, online data sources, open source software, mapping and GIS technology now allow individual users to turn epidemiological data into public health maps and analyze them.[80] Increased participation and transmission of information supports the need for visual analysis.

The 1990s witnessed the emergence of geographic information systems (GIS) and an increased interest in geospatial analysis in the medical health field. The Pan American Health Organization Health (PAHO) offers training workshops, and public databases, promoting GIS applications in epidemiology for "technical cooperation and methodological development" in public health.[81] In 1993, the World Health Organization (WHO) founded its GIS and Health Program to promote the visualization of statistics and strengthen global disease surveillance. The U.S. Agency for Toxic Substances & Disease Registry has also been experimenting with GIS in public health to improve health capabilities, assist in surveillance and the earlier detection of communicable diseases.[82] The U.S. Centers for Disease Control and Prevention (CDC) and the U.S. National Center for Health Statistics offer publicly available statistical data bases and promote free software and employ GIS for public health.[83] With urban populations increasingly interacting and creating data and sharing locally informed, participation-based knowledge, there is potential for new insights into urban public health issues. This democratization of data and new tools of visual and geospatial analysis creates opportunities to create evidence and advocate for changes in policy. Spatial and information mapping provides urban inhabitants, researchers and policy makers with the tools to frame our visual filled and data driven world.

Urban living forces many changes in human behavior and lifestyle that affect disease and increase health risks. Cities are generally characterized by "high levels of tobacco, smoking, traffic injuries, fatalities and adult obesity," and typical urban living tends to lead to obesity, increasing risks of high blood pressure and type 2 diabetes.[84] Yet, within cities, there is simultaneously easier access to health services, education and financial and social services than in rural areas.[85] The problem arises when such services are insufficient, poorly targeted, or inaccessible. Given the widespread challenges and varied nature of urban public health disparities, visual and spatial research and analysis can provide insights to overcome lapses in policy priorities, education and even resource allocation. Are there lessons to be learned from the relationships between urban design and individual health? Can research insights and visual patterns inform for instance how urban sprawl makes communities less healthy people? These may be addressed through visual research and analysis.

> **vi·su·al (n):** "attained or maintained by sight."[86]
>
> **vi·su·al·i·za·tion (n):** "formation of mental images; the act or process of interpreting in visual terms or of putting into visible form."[87]

Visualization is the process of interpreting and communicating something in visual terms. It refers not only to the end result of a visual, but the means by which information and data is analyzed. Visual research, including data visualization, can easily be communicated to populations living in urban and built spaces, while assisting in culturally specific health education and information provision. Visual mapping can often reveal layers; by visualizing the problem, new solutions can emerge. Visualization further allows for imagined possibilities and changes before the steps can be taken to achieve them. The CDC and the University of Pennsylvania focus on visualizing health data, highlighting that the mapping of "geo-referenced health statistics" to provide insight into "health-environment-behavior interactions."[88] Information for public health can be derived by visualizing epidemiological trends and patterns, as well as identifying clusters of mortality on two dimensional maps, which can them be compared by locations to distributions of toxic or hazardous agents.[89] Visually exploring spatial associations prompts new hypotheses about previously overlooked causal relations; it also allows for their verification and evidence – for example, cancer clusters.[90] GIS as a means of visual research can overcome the limitations of "static paper maps," and is useful to evidence epidemiological hypotheses.[91] The contemporary complexity of urban public health requires learning from the past but moving from traditional, 2D research towards 3D research and analysis for human health and well-being. Visualizing data and health statistics is part of addressing the multidimensional nature of urban public health requirements and urban health entails looking beyond epidemiological statistics and data.

Visual research can play a role in addressing diverse and multifaceted public health needs in developing and developed world cities. This is achieved by visualizing scientific data as well as social and economic indicators; systematizing data and information from democratized sources; strengthening health informa-

tion systems with geographic information systems; using information and analytical design to create evidence based arguments; information design to educate and communicate information to urban populations; and visualizing information to overcome gaps in research and analysis (including urban planning/housing issues); advocating for policy changes; and securing effective policy change by providing visual evidence. In order to understand the policies and plans that need to be researched, we must explore prominent urban processes and factors influencing urban health and well-being. The diverse issues faced in urban areas of the developing world need to be visualized, "visibilised", and addressed on the basis of evidence.

The benefits of GIS as an example of visual and geospatial analysis build upon principles of basic cartography and visual research. By including the dynamic aspect of data visualization to reveal linkages and providing a platform to spatially map data, GIS presents an opportunity to considerably extend the role of cartography and maps for public health analysis.[92] Harvard University's Public Health website notes: "GIS can be a powerful tool for analyzing and displaying data about the environment. In many cases rich sources of data are available from federal, state, and local government agencies and private sources. In using GIS data for public health research, it is important to have data with sufficient detail to study the exposures of interest. Research on the impact of the environment on physical activity suggests that the characteristics of the environment within an easy walk from people's homes, schools, and work might influence their level of physical activity."[93] The website notes however that, "obtaining the detailed and neighborhood level GIS data to study the role of the environment in physical activity is challenging."[94] Nevertheless, GIS projects in a variety of academic fields are on going at Harvard University—evidence of the potential of geospatial analysis for a variety of purposes.

Geo-spatial and visual analysis for urban public health is crucial: whether in terms of epidemiological mapping and surveillance; education and health information communications; health systems and services mapping; green space and walk-ability; ratios of the built environment air pollution monitoring; allergy, nutrition, and food content and standards; urban policies and processes; or green constructions vs. sick buildings. All these factors impact the health of urban inhabitants. A dramatic shift and new creative ways of thinking about urban public health is therefore needed. Beyond simply making such issues visual and visible they can also highlight overlooked patterns and cycles. Showing what is visible and existent, also demonstrates the areas that are overlooked. By incorporating aesthetics, visual and spatial evidence can become meaningful, engaging and informative.

AESTHETICS AND DATA VISUALIZATION FOR HEALTH

> **de·sign (n):** "to create, fashion, execute, or construct according to plan"[97]
>
> **aesthetics (n)**: "a branch of philosophy dealing with the nature of beauty, art, and taste and with the creation and appreciation of beauty"[96]

Edward Tufte's thinking in his books showcase the importance of aesthetics and visuals in research methods. His work explores the importance of clarity, context and information design to engage, analyze and explain complex information. Aesthetics have the power of engaging viewers through sensory or emotional appeal, including design, to affect or relate to a communities sentiments and taste. By combining elements of aesthetics and design into visuals urban public health researchers and practitioners can address specific and often overlooked aspects of urban public health—including emotional, mental, and psychological well-being. Moreover, they can affect behavioral change through efforts like social marketing and interactive media.

The very act of mapping is in itself an art that challenges the power of those who control policy and planning, sometimes at the expense of transparency and accuracy. What is chosen to be mapped or documented—and chosen to ignore—can and does have an impact.[97] Visuals such as maps have the power to engage a new audience, educate and create awareness. Spatial and information mapping can highlight the overlooked or make "the invisible visible." Gaps in urban public health can therefore be overcome by information design and spatial analysis. Meanwhile, forensic or subversive visualization can be a form of activism to advocate for changes in policy.[98] Engaging urban communities to uncover issues affecting the health of its constituents is possible through spatial and information mapping. The needs and issues, as well as how they can be overcome, can best engage and inform viewers via design and aesthetics. Information design and aesthetics which includes mapping—are tools to promote visual information, education and advocacy—with the ultimate aim to change policy.

The role of architects and urban design is in the realm

of designing and planning healthy and livable cities. Urban designers and urban planners play a pivotal role in creating healthy communities and environments. The development of "sewage and sanitation systems in the late 1800s and early 1900s, not medical intervention, has led to the most significant reduction of deaths and disease in the 20th century."[99] Conversely, urban planning is increasingly being criticized for creating unhealthy environments.[100] In the UK, physical activity has decreased as a result of changes in the way populations travel and move: "The decline of walking and cycling has coincided with the spread of the built environment" and increased use of cars and public transport. This has led to increased incidence of type 2 diabetes, coronary heart disease and other lifestyle ailments. Urban noise too affects mental health, and people found living close to greenery like trees and well-designed public spaces were "happier" than those living in more forbidding looking buildings—and the lowest quality public spaces are disproportionately located in the poorest areas. Planning and design can reinforce social barriers by keeping people apart rather than by developing mixed communities."[101] This evidence shows that an urban built environment and the health of its constituents are linked and mutually reinforcing. As such, urban planners, architects, and designers have a crucial task in promoting aesthetics with problem solving. And the role of design in approaching urban public health from a client based, problem solving dimension—while aesthetics can be used to communicate and educate health information on multiple levels through colors, symbols and images—ought to be further explored. Conversely, design as an intervention that is led by aesthetics can be a crucial tool in informal urban spaces, which lack infrastructure and maintenance—thereby affecting human well-being and health.

Visual analysis can address the health communication, educational and analytical aspects of urban public health. It can be used to create compelling evidence, to advocate for changes in policy, inform resource allocation and educate individuals for behavior. There is significant health, scientific (epidemiological), economic and social data that can inform individuals, communities, and surveillance systems. Such quantitative research and the visual display of this information are crucial to urban public health. While spatial research and analysis relates to health systemic issues such as urban infrastructure, the visual representation of economic and social indicators such as population density, health indicators, and medical statistics are increasingly important to inform complex urban health issues. Visual research, including data visualization, is easily communicated to populations living in urban and built spaces, and can assist in culturally specific health education and information provisions. Visual mapping can reveal layers; by visualizing the problem, new solutions may emerge.

From these examples, clearly urban public health research, policy and analysis can benefit from spatial and visual research. Specifically, by employing GIS to explore ratios of built environment to population dense areas, correlations between HIV/AIDS and income, infrastructure maps and planning and visualization of health data, strengthening of health systems. Visual and spatial evidence can advocate for changes in policy and provide insights that might often otherwise have been overlooked. Data visualizations allows for ease in terms of seeing the concepts in a more interesting, and often more useful manner, by relating them to surrounding concepts. It can demonstrate how lower income neighborhoods in cities might be subject to higher rates of asthma and STDs for example. Or, how the direction of wind might affect air pollution levels in certain neighborhoods. Visual analysis is important for the geographical and educational aspect of urban public health. Visual analysis can create compelling evidence that can be used to advocate for issues and changes in policy or individual behavior. Visual language is also easier to communicate to populations. The urban dimension of public health highlights the importance of spatial analysis, an inherently visual field.

Participation through mapping allows for new data sources—while there is already significant health data available for quantitative research—medical data, epidemiological as well as indicators such as mortality rates, income etc—there is a need to look beyond quantifiable and scientific information. Spatial analysis relates to health systemic issues such as urban infrastructure (including sewage pipes), population density, health indicators, and medical statistics. These are crucial to inform research, knowledge among communities (in terms of behavior change), and advocate for policy. Recognizing the influence of multidimensional issues such as poverty and education, which also affect individual and community health is important. Visualizing patterns and cycles is important, as is spatial analysis and contextualizing the various health determinants in urban spaces.

TRANSCENDING DICHOTOMIES AND BOUNDARIES: VISUALIZING KNOWLEDGE AND INFORMATION

> *Science and art have in common intense seeing, t he wide-eyed observing that generates empirical information.*
>
> *—Edward Tufte*[102]

We live in a visual world: our perceptions, understanding of our surroundings, the information we absorb, the signals we use to communicate and inform one another are overwhelmingly visual: particularly in urban spaces, where surroundings are designed and constructed, the key in this fast paced world is visually informed information. John Berger has emphasized the importance of constructed visuals and their perception and impact on human behaviors. Edward Tufte's work demonstrates the powerful ability of visuals to quickly yet coherently convey complexity. The language of research and analysis must also grow with the transformations in media and the growing role of branding and the global visual culture. Exploring the role of design, data, and information visualization and aesthetics will be crucial to the future of evidence-based arguments. Designers currently grapple with the publicly available data, but in the discussion below I will show how systems for health information, geography, community mapping, the visual displays of data can overcome gaps in research, data collection, and analysis, while serving as tools to advocate for policy change.

Edward Tufte's views on applications for analytical design principles ring true when thinking about visual, spatial analysis, and mapping for urban public health: "The fundamental principles of analytical design apply broadly and are indifferent to language or culture or century or the technology of information display. Nearly everyone

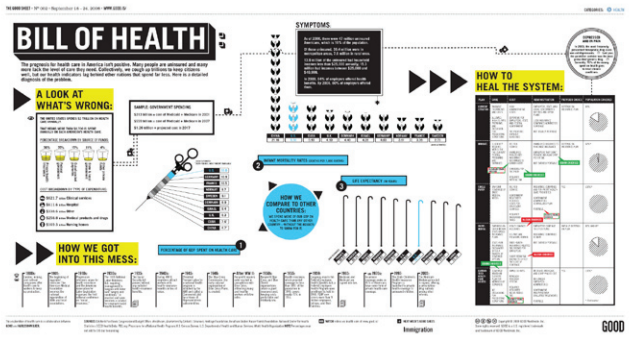

FIGURE 2: *"Bill of Health" by Good Magazine and Karlson Wilker (2008).*

everywhere, one way or another, reasons about causality, makes comparisons, navigates through 3D space and time. The principles are applicable to the design of the first map scratched in stone 6,000 years ago, and also to modern scientific displays. On both that stone and that computer screen, it is necessary to escape the flatland surface to compare multivariate data, to integrate and document evidence, to reason about dynamics, mechanism and causality."[103] The visual language- through universal—must be informed not only by geography, but also by cultural and knowledge clues that relate to the urban communities and populations whose health are being explored.

The democratization of the tools to generate data comes from a need to make sense of complexity, solve dilemmas, and show patterns, cycles and processes that might often be overlooked. *Good Magazines*' "Bill of Health"[104] for instance helped inform decision makers and voters by creating visually engaging the information. They allow links to be identified in the health system and how decisions can be affected and changed—revealing layers of complexity.

Mapping and information design tools are thus crucial to public health. Mapping is a means of clearly displaying information and allowing for its analysis. It can address the tremendous complexities of urban studies and life, including urban public health. It can demonstrate the density of urban spaces and buildings, show the extents of subway and public transport systems, chart the extents of infrastructure, visualize medical and epidemiological data, map services and access points, and highlight lapses in population surveys. The gaps in data can indicate groups being overlooked and areas being ignored in terms of their development. Mapping can be used to show flows and connections via data visualization and serve as a tool for brainstorming, the gathering and display of ethnographic information.

Design and aesthetics highlight the importance of visual perception and understandings. The spatial and visual dimensions form but one part of the urban health fabric which needs to be explored. Aesthetics appeals to us in a media and visual dominated world. Designing an approach includes a client-centric, problem solving approach that is crucial to public health. Assessing the needs of communities and devising interventions and ways to address them—for instance games and social marketing—reveals that good design can be used for broader social benefits. Information design that is targeted and community centric can play an important role in support of health education. Mapping, aesthetics, and technology can help overcome challenges and gaps in urban public health.

GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Geographic Information Systems (GIS) are a tool for geospatial analysis, that: "integrate hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information."[105] They can systematize and trace links between urban data, including density, infrastructure, networks, access to water/natural resources, health systems and services availability, and visualize epidemiological data, and medical statistics.[106]

GIS or geospatial analysis for medical informatics purposes involves mapping the spatial patterns of health services as well as disease data, which is closely linked to public health[107] GIS integrates spatial health and medical data to support decision-making and resource allocation.[108] It has been used to strengthen the health and medical fields through "measurement, mapping, monitoring, and modeling" as demonstrated by Cowen in 1990.[109] GIS has also enabled hypothesis generation, conflating geopolitical and spatial boundaries to help analyze smaller urban spaces.[110] Verhasselt's work (1993) shows that these systems open up "possibilities in ecological associative analysis,"[111] vital for urban public health and its environmental component. In thinking of the city as its own urban 'organism', GIS allows the visual exploration of urban linkages and complexities from a geographic and spatial dimension.

In our technologically dependent world, GIS must to be used with a degree of caution and skepticism, particularly in terms of the quality and accuracy of results it can generate. GIS is still vague in terms of its definition and "universal acceptance," and Matthews (1990) demonstrates that using GIS techniques by has been known to "overshadow research questions."[112]Albert also shows from the work of Taylor, Heywood and Twigg in the 1990s that data employed in GIS suffers from being "intensive, inaccessible, incompatible, and inaccurate."[113] Thus, the issue of quality and reliance on technology—particularly for developing world cities which still lack communications infrastructure in the face of the digital divide—means that GIS and its usefulness must be approached with caution. At the same time, however, the democratization of data sources and the promotion of knowledge generation and participation are part of the reason why GIS holds such promise. Its use must be approached with a cautious optimism.

GIS APPLICATIONS FOR MEDICAL CARTOGRAPHY

Before discussing the use of GIS for urban public health, it is useful to summarize literature in the field of medical geography, which applies geographical concepts and techniques to medical health problems.[114] While this field lacks the urban dimension, it overlaps in important ways with health and public health. It shows how the blurring of disciplinary boundaries can more effectively address the health of urban populations.

John Snow's map was the earliest example of geospatial mapping to trace and understand disease transmission. Today, trained medical geographers and medical/health practitioners regularly use geospatial mapping technologies to understand the spread of diseases such as HIV/AIDS, and to understand the determinants of mortality in urban areas. Komatina has explored the concept of medical geology and relationships between geography and human health.[115] He highlights methods from the 1993 Handbook of Medical Geography on various approaches relating to the visual display of space, including modeling and statistics, resulting in the creation of atlases of health for instance.[116]

Komatina showed how cartographic methods evidence a shift in the field of purely medical and scientific approaches. While medical cartography has been used to "determine global disease distribution," it has been evolving since its first use in the 1850s—away from biological and medicine and more towards the environmental and social determinants of human health. Mapping therefore offers opportunities to graphically project environmental concerns, including the negative factors that influence human health, and the geographic locations of health services, resources and other "health stimulators."[117]

GIS applications for medical cartography include mapping potential disease and illness outbreaks and providing data to strengthen health applications. To address urban environmental health, GIS was used for risk assessment; for instance, in 1992 Wartenberg showed how it was used to determine exposure rates to lead poisoning in neighborhoods which can be attributed to socioeconomic status, soil contamination, and air contamination.[118] It was also be used to produce maps of water wells and associate residences that are using a contaminated aquifer by Stallone et al in 1992.[119] GIS can also analyze patterns of cancer to establish health risks associated with mortality—for example, research by Lam in 1986 into stomach and esophageal cancer and its ecological association lacks due to the environmental data requirements.[120] In nyc, the wtc lawsuit is now emerging because of locally informed mapping and testing of air quality to challenge statements made by the Environmental Protection Agency about safety. A similar example of poorly extrapolated data was in India in 2007, where HIV/AIDS prevalence by the UN were shown to have been overestimated. Strengthening locally informed data sources for data is crucial for effective urban public health policy and resource allocation.

Geographic information systems can also examine spatial patterns of health care services and disease, by analyzing distribution; location/allocation; monitoring and prevention; surveillance, modeling, and simulations; and cluster analysis. Albert's work from 1995 and 1997 discuss MapInfo® which used GIS to analyze physicians' medical practice locations.[121] By mapping physician database records in various medical fields, GIS showed that secondary and tertiary medical locations had "lower population thresholds than primary medical locations," and more specialized physicians were also shown to often travel greater distances between locations than less specialized physicians. Such information can be crucial, especially given weak public health and medical systems in many parts of the developing world.[122]

GIS has a role in disease preparedness, natural disaster and emergency response applications, which also inevitable link to urban public health. Geographically, disaster and emergency concerns remain unique or increasingly complicated in specific urban spaces. GIS can also be used to conduct search and rescue activities; urban mapping was used post-Katrina in New Orleans to help researchers identify neighborhoods that were inhabitable and uninhabitable. Color coded schemes can easily visualize and help the targeting of resources and their allocation. Some GIS applications model can also simulate health hazards. For example, GIS was employed to study an industrial plant producing toxic emissions to indicate areas having an excess risk for cancer.[123] Thus, even in its medical applications, GIS has the potential to address environmental and social determinants of urban public health and well-being.

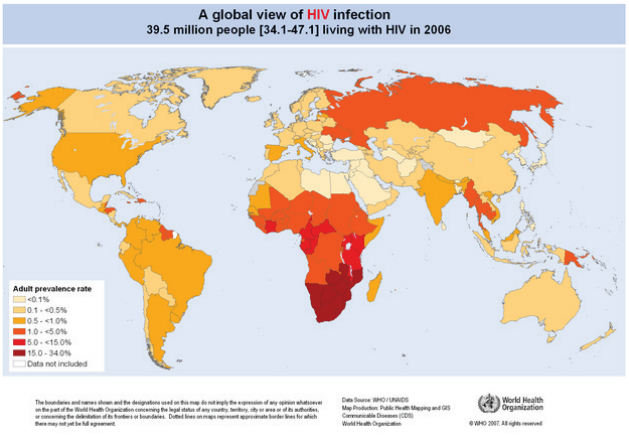

FIGURE 3: *Global HIV Infection map by the World Health Organization*

Zwarenstein et al. demonstrated that GIS can be used to explore the social determinants of health, and assess the effect of removing race restrictions on hospitals in Natal/KwaZulu, South Africa in 1985.[124] Their research "visually and spatially explored population/bed ratios for blacks, which were shown to be high even after removing race restrictions on hospital admissions."[125] Finally, in mapping of epidemiological data in its spatial contexts, geographic information system have been used to monitor measles in 1991, epidemics like HIV/AIDS in the 1990s, and access to health care resources for the homeless (for example Lee, 1996).[126] Epidemiological data—unlike medical statistics and databases—can reveal crucial trends, patterns and information when input in GIS. Beyond just medical informatics and visualization of health data and outcomes, there is the potential to use GIS to inform effective preventative health measures.

GIS APPLICATIONS FOR URBAN PUBLIC HEALTH

> *The application of* GIS *is limited only by the imagination of those who use it."*
>
> *– Jack Dangermond, President of* ESRI[127]

GIS and its applications in the medical health field can be extrapolated for urban public health, such as environmental risk monitoring and disease outbreak preparedness. The CDC points out that GIS "digitally links data and geography to create maps, providing a useful way to reveal and view spatial and temporal relationships among data. By understanding geographic relationships that affect health outcomes, public health risks, disease transmission, access to health care, and other public health concerns. GIS is being used with greater frequency to address neighborhood, local, and international public health issues."[128]

GIS may be used for health information visualization for public health "information management, broadcasting, data management, statistical analysis," and to support decision making.[129] Using geo-referenced data, such as specific locations designated by zip code, latitude and longitude, street address, and geopolitical boundaries, public health factors and determinants can be visualized in GIS distribution maps—"crucial to construct visible public health information system."[130] Specifically for public health, GIS can be used to visualize and analyze epidemiological data, resulting in important findings to prevent further outbreaks and track the various factors which influence the health of urban populations. It allows for timely detection (and therefore response) to public health disease outbreaks,

based on epidemiological surveillance systems.[131] Clear and concise data visualization allows researchers and users to investigate and communicate information by generating graphs, maps, plots.[132] Rather than relying on computers for analysis, human interpretation quickly separates statistically significant epidemiologically data to predict and manage disease outbreaks.[133] Participation by communities to address their own health and well-being is key.

GIS offers effective surveillance systems to aid epidemiologists in deciphering large amounts of data in a timely and cost effective way.[134] By identifying factors influencing potential disease outbreak situations, it can link to helpful information and determinants, including geographic area, population, etc. This is important to address the environmental determinants of urban health. GIS can track epidemic outbreaks and analyze trends over time and at specific geographic sites, allowing for additional layers of analysis including income, population density, spatial density, crowding. Moore in 1991 demonstrates that by generating time series plots, epidemiologists can examine monthly, yearly, seasonal trends from incoming data streams.[135] Thus, the geospatial visualization of data can help users to identify the significance of any recent data anomalies.

Visuals are easier to absorb, communicate and understand events over time and space.[136] Moore's work demonstrates that viewing a map generated by an integrated geographic information system allows epidemiologists to identify "clusters of increased activity or determine if the increases in data are randomly dispersed. Geospatial data visualization can assist public health in tracking an outbreak, by creating maps of received data overlaid with infrastructure, water sources, or hospital locations."[137] By making it faster and simpler for epidemiologists to analyze large amounts of data and simultaneously view temporal changes and spatial distributions of data, GIS can unveil patterns in seasonal or weekly trends of a data selection.[138]

GIS is crucial as a public health application; it can improve and strengthen public health capabilities and assist in timely epidemic outbreak detection as compared to traditional means.[139] It provides new sources of evidence for arguments. When issues are visualized as maps they add a layer of geographic and contextual specificity. GIS can serve as a mechanism for community change by revealing dimensions to urban public health that advocate for more effective resource allocation, health systems and provision of information to urban populations. Since GIS technology is becoming more accessible and widespread, it is crucial to learn more about the effect of geography on health and well-being and highlight importance of cartography as a tool to convey clear and concise information in a spatial context.

Spatial analysis can be extremely useful for public health research and policy, particularly urban and environmental aspects. It can show causal factors or associations between disease and place that may imply that populations living there "either possess inherent traits that make it more susceptible to disease or experiences elevated exposure to a risk factors such as air pollution."[140] Such analysis helps to further identify how populations adapt and relate to their environment, knowledge that could lead to "improved understanding of how people perceive and avoid health risks of environmental origin."[141]

GIS AND PUBLIC HEALTH MAPPING

In 1993, the WHO established its Public Health Mapping and Geographic Information Systems (GIS) program to change the way "geographically linked information can be used to monitor disease, improve health care, and save lives."[142] Many countries currently use mapping or GIS and related technology to trace the "geographical spread of disease and populations at risk, analyze data and monitor trends, identify un-met health needs, and target the delivery of health interventions such as medicines, vaccines, or mosquito nets."[143] This application of GIS is used to provide evidence that can inform policy and responses to public health requirements.

Public health mapping enables the "standardization of surveillance data at multiple levels and across diseases."[144] It also allows for the analysis of health related data from other sectors and perspectives: education, environment, aid amounts. Specific populations can be targeted, located and profiled without time consuming and sometimes expensive field research.[145] At the same time, populations and communities can be encouraged to participate (and also engage/reflect) by providing data and participating in disease surveillance and local knowledge gathering efforts.

In looking at urban and environmental health, the issue arises of geographic specificity of vulnerable populations: "people at risk of most communicable disease often live in geographically isolated communities, usually have poor access to information and health care and are generally served by poor transport and education infrastructures.[146] To reach these populations to organize and coordinate appropriate responses and putting their problems "on the map" literally, demonstrates the power of information visualized and mapping efforts.[147] Finally, the WHO mapping program argues that GIS can help establish multi-sector links and enable information shaping for human development ends.[148]

GIS and spatial analysis allow the mapping of "basic demographics and health profiles, access to health and education services" and are key to the planning of healthy urban development. Mapping systems provides multiple sectors to view a comprehensive picture of health situations faced by urban communities. The WHO further shows how public health mapping can be used to facilitate global partnerships, data management and ease of communication; address the overlooked and vulnerable populations' facilitate collaboration among sectors to provide information that is necessary for development; global and national surveillance to strengthen "first line defense", and create "dynamic atlases" of public health for improved decision making and resource allocation.[149]

Publications such as the "Atlas of Mortality" or the mapping of cancer clusters, for example, look at various regions and communities, given the idea that "We are where we live."[150] Urban planning has a role to play in creating and managing the built environments we live in. It has an influence on our health and our ability to maintain good health."[151] One can examine urban and environmental health issues spatially, including greening, locations of hospitals, sites of pollution, information about municipal regulations about buildings. However, these are issues relevant to the formal city. The informal city—which dominates the developing world—lacks many of the protections of health and security, including formal jobs, thus liming health and limiting "freedoms" and capabilities, in the words of Amartya Sen.

GIS informs environmental health decision making, for urban public health. The University of Iowa shows that GIS and Public Health has risen to prominence because health surveillance practices and service allocations need to be more sensitive urban community needs in localized geographic areas.[152] Geographic and health information and data collection, storage and manipulation has undergone a "revolution" with the development and availability of GIS software and systems.[153] Policy makers and health professionals can "benefit from further education in this area, and with their new knowledge, they can influence the progress of health surveillance, environmental health assessment and the geographic allocation of health resources."[154] According to the University of Iowa's website, "the improvements contributing to rapid adoption of GIS include strengthened health information systems and increased availability of geo-coded health data; the availability of digital files containing layers of geographical information; the availability of environmental risk and exposure information; the nature of GIS technology as inexpensive and easy to use as well its increased functionality to run on a wider range of hardware; finally methods of spatial analysis are becoming available as separate software modules or are embedded in GIS."[155]

HEALTH GEOGRAPHIC INFORMATION SYSTEMS: YEMEN

Geographic information systems (GIS) can be used as an epidemiological tool when adapted to health systems, and can quickly analyze data with a minimal financial investment and manpower.[156] The development of Health Geographic Information System (HGIS), suggests that increased availability of GIS software applications can be an invaluable tool to Public Health professionals. Though limited to the visual representation of data, HGIS can be a useful tool for "risk assessment, decision making, intervention evaluation and health planning."[157]

Health Information Systems (his) are used in countries to organize sensitive medical and health related data. In Yemen, usaid has been using GIS to share information and resources to improve health resource allocation to explore gaps in the 'availability and accessibility' of immunizations services in the Amran Governorate.[158] Health information tools and applications developed by Health Systems 20/20 allow people to "visually explore patterns in health indicators and identify service gaps, such as staffing, drugs, equipment, infrastructure, underserved populations, and inaccessibility to health facilities, in order to prioritize resource allocations."[159] This can be transferred to other urban contexts and allows decision makers to access data to better inform policy and resource allocation. It also creates atlases of health facilities , which includes maps of precise geographic locations, photos and information about health facilities—for those who cannot access computers or GIS. In this example, the GIS helps to inform better decisions at a national level—yet holds potential for use at a local level. Health officials and policy makers can use this evidence base to allocate resources, instead of simply guessing or estimating his/GIS data in Yemen is now being used to estimate population, children and health facilities in various local districts for better and more effective resource allocation.[160]

PARTICIPATORY MAPPING TECHNOLOGIES

The *Flu Tracker* launched by Google in 2009 is an example of visual and spatial analysis of trends. Following the H1N1 swine flu outbreak in 2009, Google built an experimental Flu Trends monitoring model for Mexico. Unlike Google Flu Trends for U.S., the experimental Flu Trends for Mexico was not built using historical data on flu symptoms, using "aggregated search queries" likely to be associated with influenza.[161]

Flu Tracker is an example of technology and visualization overcoming the limitations of tradition for public health. It allows users to generate searches and data to track flu trends around the world—and has evolved to address pressing needs. According to Google, "traditional flu surveillance systems take time to collect and release surveillance data, but Google search queries can be automatically counted very quickly. By making flu estimates available each day, Google Flu Trends may provide an early-warning system for outbreaks of influenza. For epidemiologists, this is an exciting development, because early detection of a disease outbreak can allow for flu shots to be taken in a timely manner and help reduce the number of people affected. If a new strain of influenza virus emerges under certain conditions, a pandemic could emerge and cause millions of deaths. Up-to-date influenza estimates could help public health officials, health professionals and individuals to better respond to seasonal epidemics and pandemics.[162]

Participatory mapping provides a framework or tool for the democratization of data, allowing sources to be relevant and helpful. Google Maps, Google Earth, and other open source or Web 2.0 technologies enable engagement that challenges the power and control over medical maps and scientific or health knowledge. The Global Disease Alert Map Health Map monitors infectious diseases on a global scale. Meanwhile, websites such as Daytum allow users to collect and communicating daily personal data. With iPhone applications, global positioning system (GPS) technology and open-source GIS software, comes the potential to now track where we are, what we eat and how it influences and impacts us. This addresses nutrition and individual urban behavior and health determinants such as condom use.

The Million Dollar Blocks Mapping project is another example of GIS employing criminal justice data and statistics to make visible the "geography of incarceration" in cities including New York.[163] The aim was to understand the spatial dimensions of public policy and its implications for cities.[164] It is an example of GIS and mapping to serve as an invaluable monitoring and evaluation device and

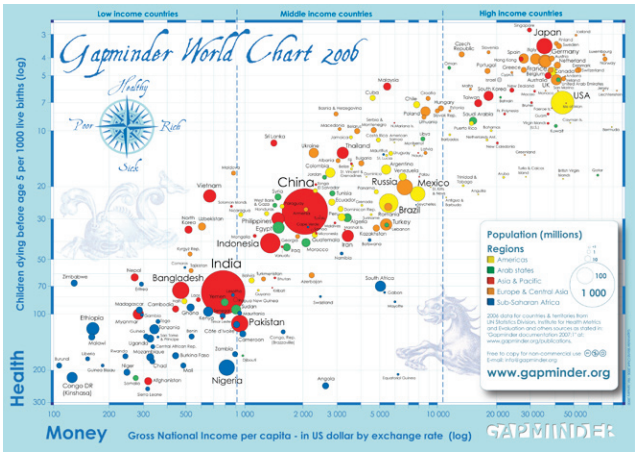

FIGURE 4: *Gapminder Health and Money Chart*

feedback loop. Using tools of spatial analyses and visually representation to reveal "previously unseen dimensions of criminal justice and related government policies,"[165] the project establishes a precedent to explore the linkages and correlations between social determinants and well-being, and spatial correlations between income, gender/race and HIV/AIDS—at an urban or sub-national level.

Thus, visual, spatial analysis and the tool of mapping can establish investigations, correlations and clarify research and information via analysis, geographic context and the visual displays of information. The links between various disciplines including geography, medicine, public health, urban studies, urban policy, natural resource management, design, architecture, environmental sciences, public policy, urban planning, technology, and computer science—all meet under the banner of addressing human health, development and well-being.

Ranging from advanced technology such as GIS to simple information mapping, Mark Lombardi's work allows the viewer to infer and make connections. He employs information diagrams to show links and flows and interconnections. While not explicitly about public health, he shows flows of money among government and terror networks which are not being used for well-being. The works of Lombardi links factors and reveal social and economic networks—which are crucial to see who governs what in our public health systems to forge effective public and private partnerships and links.

Gapminder maps show the increasing disparity between developed and developing countries and the relationship between income and health. The Gapminder website allows individuals to use existing data in a non-investigative approach to explore information and visualize data. The "Health and Money" map for instance shows useful

correlations over space and time, and is a simple and effective means of making an argument and conveying information. It compares countries and territories by national income and health, showing important links yet also overlooking many urban/local subtleties. Meanwhile, *Good Magazine*'s "Bill of Health"[166]—as an information diagram, provides a detailed diagnosis of the healthcare problem in the USA by simplifying a complex issue through visual display of information. The website of debategraph.org allow users to participate in rethinking, researching and reimaging policy via online public debates. Debate graph specifically employs user-created interactive graphics to explain and encourage public participation on a variety of public issues.

Sharing of knowledge and information in this Information age is crucial and can be helpful when distilled for quality. Urban public health can benefit from research information and analysis in the fields of information design, diagrams, aesthetic information, knowledge and data visualization and mapping. Technological advances are now allowing for simplicity in terms of research and analysis and grappling with large amounts of data and information. Visual and spatial analysis allows us to re-think, re-imagine and cause change in urban public health.

Urban living undeniably affects its constituents—whether by the psychological impact of noise, the visual stimulation of ads, the calmness associated with trees, the lack of heart disease associated with walking and public transportation, the allergies relating to pollution and air quality, or the access to nutritious or preserved food. Mapping—which incorporates both visual and spatial analysis—has the potential to address and highlight current challenges and inform research in urban public health including, for instance, educating urban inhabitants about the food/nutrition content of what they are eating. Mapping creates an evidence base, links theory and practice and overcomes many dichotomies in health. It also fosters community-based urban participation and allows locally informed knowledge to create a data base for advocacy.

MAPPING FOR IMPROVED URBAN HEALTH AND WELL-BEING: BENEFITS AND LIMITATIONS

> *The only way to cope with the developing world's overwhelming problems is to build effective public health systems. Such devices monitor the health and well-being of its citizens, identify problems in the environment and among the members of its community, and establish public health practices to address these problems, including the problems of whether proper health care is accessible to all, rich or poor.*
>
> —*Laurie Garrett*[167]

We are now a "city planet."[168] New urban complexities faced worldwide—particularly in relation to health and well-being—warrant a blurring or conflation of disciplines for innovative thinking, particularly in terms of research, analysis and policy. The 21st century requires a change in the design, planning and use of cities to promote, "healthy, socially equitable and ecologically sustainable ways of living."[169] This also means creating healthy cities that do not conflict with their ecological balance or leave a devastating carbon footprint. While unique characteristics inform public health in relation to physical and urban sites, it is essential to be culturally appropriate and sensitive, depending on the "space" and needs being addressed.

Amartya Sen emphasizes a need to conflate knowledge and promote urban community participation: "The global health crisis we face today demands fresh reflection and new departures. Central to this encounter is the development and use of social and scientific knowledge. The crisis does, of course, demand dedicated action as well as faith in mankind's ability to overcome monumental adversities. But we need a knowledge-centered approach to make our actions fit the needs."[170]

Research and experience show that urban public health requirements differ between parts of the developing and developed world, as well as within countries and cities. Urban public health knowledge and information can benefit from a site and geographically specific approach, one that targets health systems, surveillance of diseases and health determinants, and education in a localized, participatory manner. Visual and spatial research can also overcome lapses and gaps in urban public health by providing clarity and context to statistics, strengthening surveillance systems including monitoring and evaluation, providing a feedback loop to inform urban policy, planning and resource allocation, as well as educating populations for behavior change.

Responding effectively to urban public health needs across the worlds requires the development of specific, clearly defined and contextually appropriate plans—which is possible through mapping. Addressing the multiple dimensions of HIV/AIDS, ensuring that donor aid for health is more effectively targeted, exploring linkages between proximity to toxic sites and cancer rates—all this is more effectively undertaken through mapping. Combined with technology, there is potential to connect multiple issues via global, local, geospatial mapping, and leveraging tools of social connectivity.

Mapping of different slices of urban public health data pertaining to a geographical area, allows presentation of a multiple of visually and spatially-based diagrams/charts for information and in-depth analysis. Such a "cat-scan mapping," to borrow a medical term, of an issue of health interest or concern, enables cross-sectional presentations that permit examination of an issue from multiple perspectives, providing a more complete, multi-dimensional view of the problem and sometimes throwing up a better diagnosis or solution.

SUMMARY OF LIMITATIONS

Visual and spatial analysis obviously cannot hold all the solutions to urban public health – but it adds much needed insights and new perspectives. There are many inherent challenges, such as risks of oversimplifying complex information or miscommunication. With individuals being able to generate and share data faster and quicker, there is the risk of obscuring valuable information, visualizing inaccurate statistics or making weak correlations. Then again, there are limitations to statistics and quantitative information in general, and to address multiple dimensions of health, it is often helpful to unpack statistics.

Another important limitation is access to and application of technologies such as GIS. However, as demonstrated by John Snow, even simple cartography or visual and spatial analysis can be extremely effective. Public health researchers find GIS a useful tool to organize and analyze health determinants and outcome data, as well for "estimating environmental exposures and displaying research results"; yet, despite advances in hardware and software which have made GIS capabilities readily available, there are barriers to learning and applying the software to specific research and geographic needs.[171]

In terms of applying and relying on advanced technologies, there is the assumption of access and availability to reliable infrastructure—but as with any tools of research, GIS and mapping must be approached with caution. Researchers should constantly be aware of the power over information and control of what is and is not shown—and how it is perceived by populations. Such sensitivity and awareness could greatly facilitate and overcome limitations to quantitative data collection and analysis.

SUMMARY OF BENEFITS

The benefits of visual and spatial research, particularly for urban public health concerns, far outweigh its limitations and challenges. Mapping holds the potential to address lapses and fill gaps in needs in developed/developing cities, because:

- Visual language transcends barriers and the attractive presentation of evidence is engaging. Maps—spatial and information—can assist in better identifying challenges and crises in the contemporary global public health system. They clarify, contextualize and deepen understanding and responses to urban health complexities, including health factors and indicators and their correlation, quantitative knowledge, deciphering medical statistics, and epidemiological data.

- Education is fundamental to change the behavior of individuals and urban (community) public health. Whether it pertains to sanitation, hygiene, health information or the means of equipping populations to address their own concerns, effectively communicating health information is crucial and often easier through simple visuals. Colors and designs can also integrate and be sensitive to local cultures, knowledge and information can assist with education—a crucial component of human health and well-being. It also overcomes low literacy, poverty, and other access discrepancies.

- Beautiful visuals are visually engaging and can form compelling, evidence based arguments that engage not only the communities affected, but also decision and policy makers. Aesthetics can be employed to make visuals more culturally appropriate and layered with complex information, Advocacy is more effective when visually and spatially informed. Evidence based on the visual display of quantitative information can inform decision-making, including policy and resource allocation by multiple stakeholders—governments, individuals, NGOs.

- With the new tools of technology, mapping can be community and individual centered, resulting in new ways to inform urban public health research and needs. By bridging individual and community preventative health via design and technology highlights crucial urban public health issues.

- Environmental health and social determinants are crucial to explore, given the importance of sanitation issues, hygiene and basic education to prevent the transmission of flu strains, and even to explore and analyze air pollution emitting from sites of high traffic congestion. Visualizing the social determinants allows the exploration of the multiple dimensions of poverty—and related vulnerabilities—and their impact on health.

- "Cat-scan mapping" of an issue of health concern can reveal multiple perspectives, providing a more complete, multi-dimensional view and sometimes a better diagnosis or solution. In this way, mapping evidence and responses to urban public health issues can offer shared experiences, lessons and glimpses into lapses and oversights as well as best practices for effective policy, advocacy, and resource allocation.

POTENTIAL OF CONTEMPORARY MAPPING TECHNIQUES TO ENHANCE URBAN PUBLIC HEALTH

Complex urban living and public health issues would benefit from visual spatial research and analysis, employing the tool of mapping. The advent and spread of the internet and Web 2.0 holds potential for the future of urban public health mapping. Mapping with communities and interactive urban and environmental health technologies can facilitate community participation and empowerment, enabling people to better address their own needs and well-being. Advances in information and communication technologies, such as mobile phone technologies, GPS and sharing of knowledge through simple visuals are effective means of gathering complex urban information and data. Conflating medical geography, cartography, urban planning, and public health reveals new opportunities to secure improvements to health and wellness.

In the developing world, persistent health concerns, such as cholera, which emanates from water contamination, need to be prioritized and prevented. Timely disease prevention can be informed by GIS applications that would perhaps also strengthen infrastructure and highlight the issues faced in informal settlements in megacities. Further, local and traditional forms of knowledge tend to be overlooked as a result of modernization and imposed forms of western medical health systems. Information mapping can easily convey important health information while community participation and urban involvement can help overcome the digital divide, especially in developing urban cities. Essential health information can be communicated to their intended recipient using easy to comprehend visuals and maps, even in locations that have limited or low rates of literacy. Visuals and maps can also overcome low literacy rates which hinder the communication of important health information, and education.

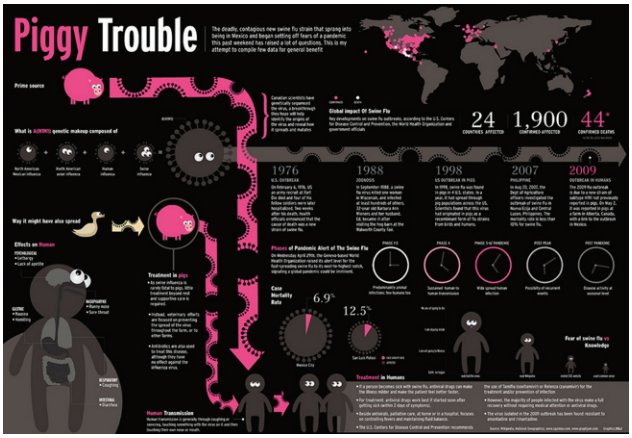

FIGURE 5: *Piggy Trouble by Raj Kamal* (2009)

Visualizations of swine flu, such as Piggy Trouble, is an example of the power of design and aesthetic to inform, educate and explain health complexity. Media outlets like the BBC have been tracking the global spread of the Swine flu since its outbreak in Mexico in 2009 and the dynamic country by country map on its website to show how Swine flu has been spreading, uses a visual timeline to put in perspective the numerous factors involved. With the WHO raising a pandemic alert, it is important and timely to explore innovative responses to public health issues[172] This is essential so as to determine gaps and distinctions in incidence and prevalence. Mapping epidemic data and outbreak indicators associated with areas where the swine flu is emerging and spreading can also facilitate the sharing and exchange of knowledge between urban areas, including best practices. Thus, the WHO situation updates and maps section, would benefit from a more aesthetical projection of the cumulative number of confirmed cases of H1N1. It could also profit by "cat-scan mapping" and projecting local knowledge and data—such as reflecting the number of deaths by city or region, cross-linking them

with international travel patterns, etc. Mapping, visual, and spatial analysis have the potential to inform, evidence and advocate for better policies and information to contain this pandemic.

Mapping can reveal the multiple dimensions necessary to effectively address urban public health. It can highlight gaps and lapses in knowledge and data, inform and address such oversights and advocate and effect policy changes. Maps can advocate for change by informing urban policy and processes, engaging communities and urban participants into a feedback loop, and source of local knowledge. Mapping visually and spatially reveals access to water, proximity to services, incomes, poverty, and freedoms. It can help improve the provision of health services; inform and educate populations of where they are and are not available; and create visual arguments for changes in policy while building social networks and facilitating partnerships to secure policy change. Information mapping and data visualization hold the potential to create compelling evidence based arguments, which can easily and quickly communicate information, transcend disciplinary boundaries, and advocate for change. Mapping can help address the gaps, disparity and needs of populations in the developed and developing world—allowing for effective resource allocation in health systems, advocating for direct health service needs and improving access. In an increasingly globalized world, these advanced technologies hold the potential to form social justice networks among developing and developed world cities.

Urban public health practitioners can benefit from information management systems that are "designed to meet the needs for specialized information and communications. Instead, they have been greatly forced to rely on information technologies designed to meet the requirements of clinical medicine or business, or have simply done without."[173] Friede et al. argue for a new category for specialized requirements for public health informatics.[174] Contemporary urban public health entails looking at the health of urban inhabitants as well as the livability of the city. It must include an analysis of green public spaces, standards and monitoring of air quality and emissions, the sciences of buildings and even construction materials. Urban planners must realize that they can do much to contribute to well-being and play a significant role in ensuring that all built environments are healthy places for people to live in.[175] Involving and immersing oneself in the urban environment offers immense opportunities for more effectively addressing urban public health needs.

Evidence-based research insights through visual and spatial research and analysis support the following aspects of urban public health and therefore ought to be creatively employed: timely disease preparedness; analysis of infectious disease transmission routes and outbreak causes; insights into environmental and social determinants of health and well-being; urban planning research affecting urban living, which include constructed walking routes, monitoring of air pollution; and finally, culturally and locally appropriate and effective health education and communications. By advancing and supporting these multiple dimensions of urban public health, it becomes possible to advocate for effective policy changes and appropriate interventions and resource allocations—towards improved human health and well-being.

Mapping technologies can direct, inform, and constrain urban development for public health needs. Additionally, conflating boundaries and "cat-scan mapping" of issues of urban public health concern can open up multiple perspectives, through incorporating design, visualization and aesthetics to create evidence-based arguments and reveal a more complete, multi-dimensional view—offering a better diagnosis or solution.

The path ahead lies in applying visual analysis and modern technologies to overcoming gaps in urban public health and securing a more effective approach to it, particularly in developing country urban habitats. Now is the time for new perspectives, new insights and new ways of thinking—to illustrate points, conflate and redraw boundaries, and literally put urban public health needs "on the map."

BIOGRAPHY

Shriya Malhotra has an MA in Cities and Urbanization from the Graduate Program in International Affairs at the New School. She is committed to applying visual and spatial analysis for medical and social science research, promoting human development and urban well-being.

shriya (n): a device that turns chocolate into international development projects

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