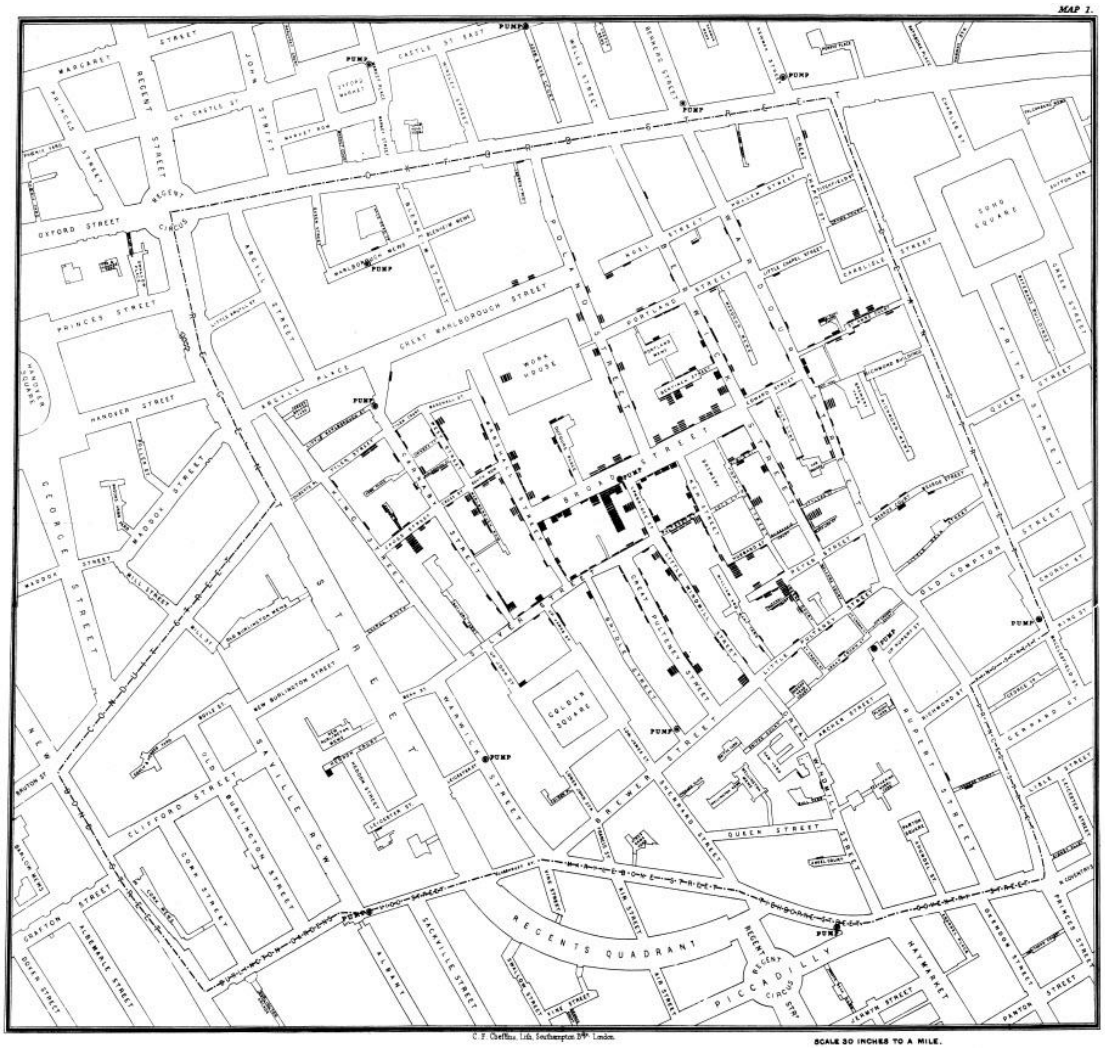
DR JOHN SNOW: CHOLERA, SPATIAL LITERACY AND VARIATION THEORY

Cholera

The year was 1854 and London was in the grips of another cholera epidemic. This time it struck in the Soho District around Golden Square. In just over a week, 578 people died of the disease prompting the authorities to act. At the time it was commonly thought that cholera was caused by a 'miasma' and spread by bad air. Dr. John Snow, a local doctor thought otherwise. He believed that cholera was caused by a poison and spread through water. To prove his theory, Snow mapped the location of all 13 public wells and all the known cholera deaths in the Soho district. Wells were represented as black circular dots while deaths were represented as black bars horizontally aligned to addresses on the road network. A dotted line represented Snow's study area.

This information was then overlaid on a based map produced C. F. Cheffins, a noted surveyor and cartographer. The Brewery, Work House and other places of interest provided landmarks to orientate the map. Based on his field notes and interviews, Snow knew that 61 of the 83 people who died obtained their water from a pump located on Broad Street. This was enough to convince the Board of Governors of St. James Parish to close the pump by removing its handle on the 8th of September, a week after the outbreak began. As a result, the outbreak quickly subsided.

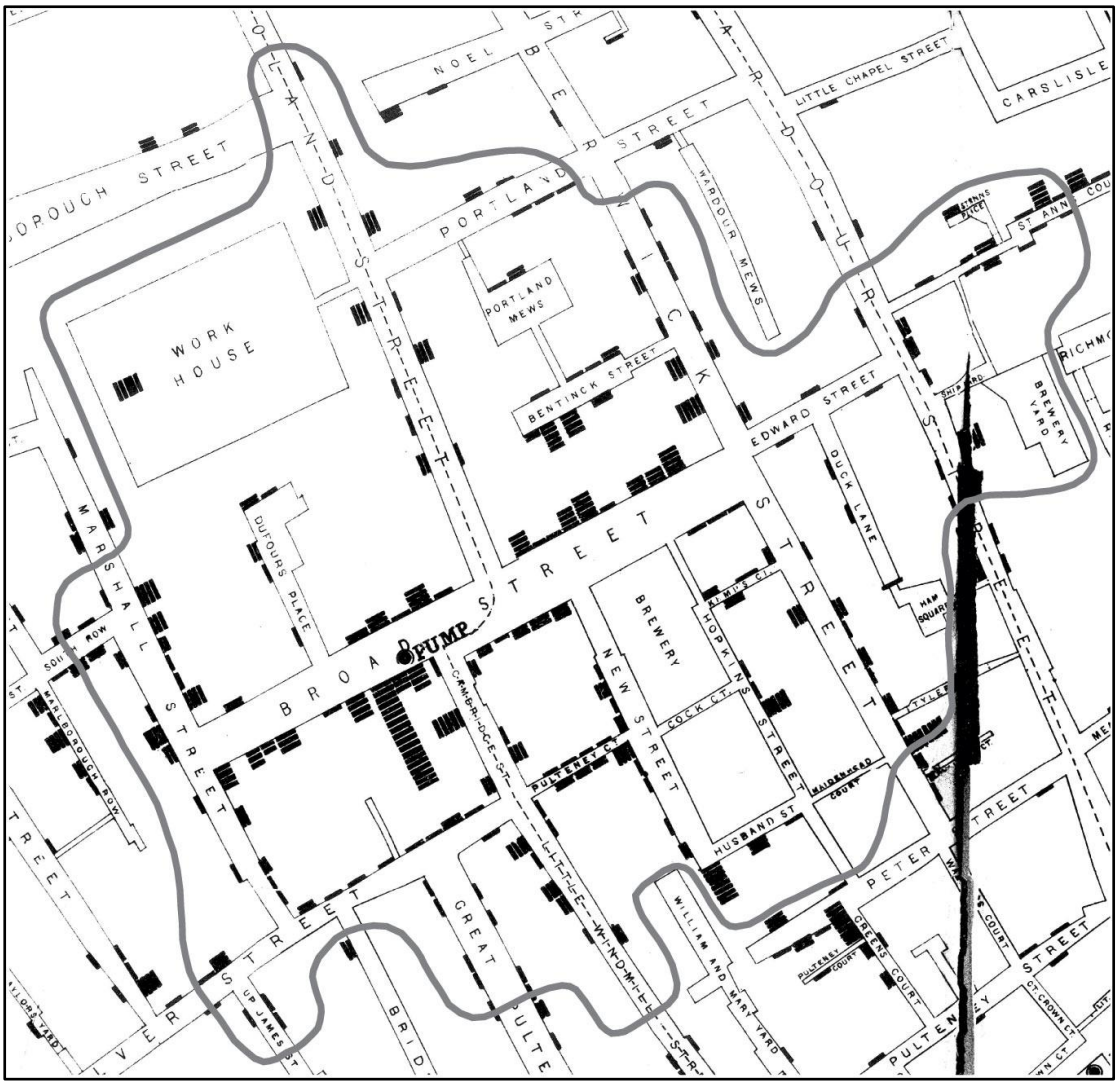


Map 1 Snow's Cholera Map.

Snow's cholera map is an early example of spatial data visualisation and visual communication (Cliff & Haggett, 1988b; Dodge, McDerby, & Turner, 2008; Koch, 2000; Tufte, 1997). Like all good maps, it told a story documenting the grim footprint of "the most terrible outbreak of cholera which ever occurred in this kingdom" (Snow, 1855). The map revealed an unmistakable pattern in the data. Cholera deaths were concentrated around the Broad Street pump standing at the epicentre of the epidemic. Visualisation also enable Snow to dig deeper into the data to investigate

abnormalities in the outbreak which helped silence his critics. He found that that workhouse housing 500 paupers just north of the Board Street pump had its own well and so suffered few casualties. Significantly, none of the 70 workers of the Lion Brewery just metres away from the pump contracted cholera as they had access to beer instead of water. Snow also found that the people who died near the Marlborough Street well drew their water from the Broad Street well because as they said, 'it tasted better'. Based on the visualisation of the spatial data, Snow concluded that cholera was a waterborne disease and that the source of the epidemic was the Broad Street pump.

Snow used a variety of proto-spatial analysis techniques to prove his theory. He identified the pump's neighbourhood by drawing an irregular polygon to represent walking distance via the road network to the pump. He reasoned that since people chose the closest pump to draw water, there would be some spatial correlation between the location of pumps and death rates. His neighbourhood analysis map demonstrated that the nearer you lived to the pump the more likely you were to contract the disease adding proof that cholera was a waterborne disease and that the Broad Street pump was the culprit. Snow believed that proximity or distance decay could be used in mapping diseases thereby adding proof to the First Law of Geography- "everything is related to everything else, but near things are more related to distant things" (Tobler, 1971). Snow concluded that cholera deaths were clustered around the well and not randomly distributed in space. In other words, there was a positive correlation between cholera deaths and the location of the Broad Street pump.



Map 2 Snow's Neighbourhood Analysis Map

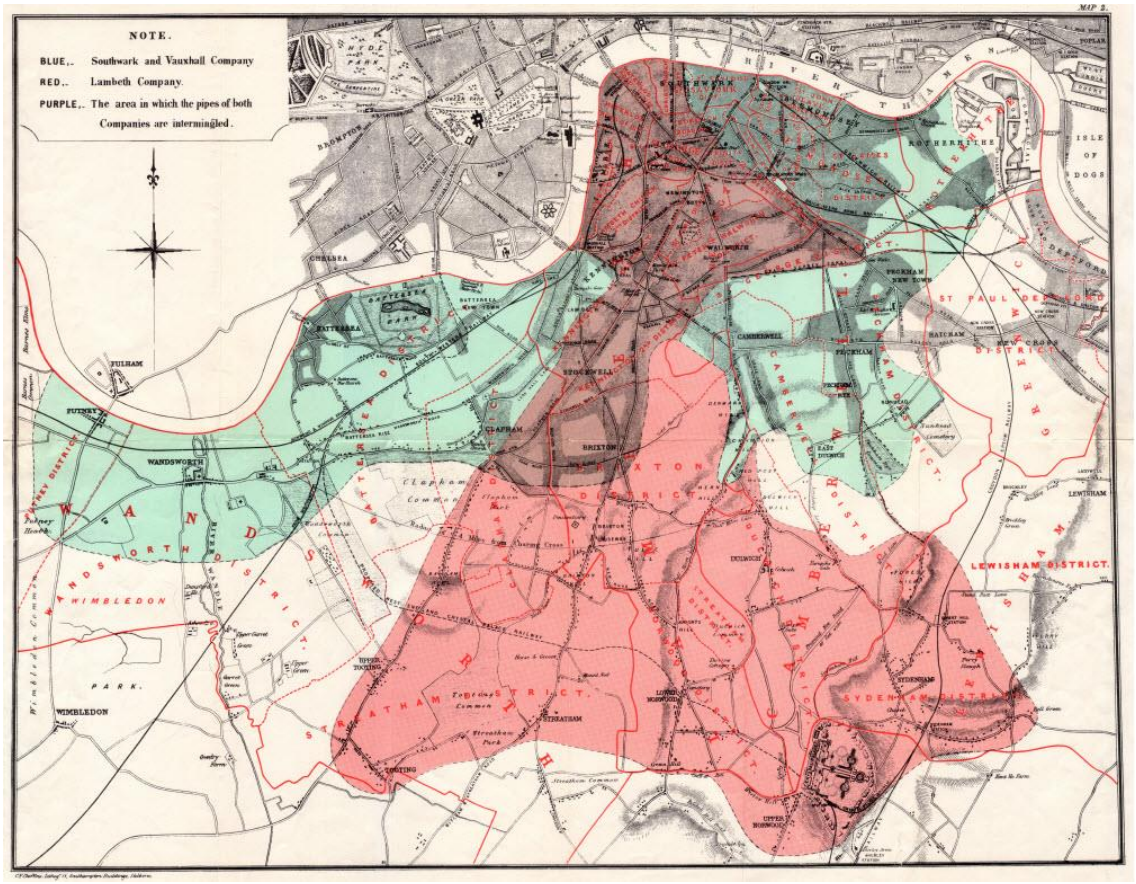
Not everyone was convinced of Snow's theory. His critics argued that other modes of transmission apart from water could be at play and besides no pathogen had been shown to exist. Such was the appeal of the miasma theory in Victorian London. Determined to prove his theory, Snow devised a grand experiment. He knew that death rates from cholera varied in London. He also knew that two water utilities, the Southwark & Vauxhall Company and the Lambeth Company distributed water to thousands of households in south London. But what he did not know was who were the customers of the water suppliers because the water network had not been

mapped. So, he interviewed households of cholera victims to determine which company supplied their water. For those people who were uncertain, Snow devised a salinity water test to differentiate the two water sources (Hajna, Buckeridge, & Hanley, 2015). Using this data, Snow was able to map the distribution of salinity values from which he inferred the service area of each company. From this Snow produced a thematic map representing the service areas of both companies which included a spatial overlap indicating a range of values due to a mingling of pipes.

The next part of the puzzle was straight forward. Snow obtained cholera mortality data from William Farr, the Compiler of Abstracts for the Registrar General's Office and overlaid it on the service areas maps. Using this technique, Snow was able to show the spatial distribution of service areas and cholera mortality rates in South London. He found that each of the water providers had different death rates. The Southwark and Vauxhall Company had a death rate of 71 per 10,000 houses while the Lambeth Company had a death rate of 5 per 10,000 houses. In other words, water from the Southwark and Vauxhall Company was 14 times more deadly than the water from the Lambeth Company (Snow, 1855). In the shared service area, there was a clear correlation between mortality rates and water source.

Using this insight, Snow developed a causal explanation to account for the variation in death rates. The Southwark and Vauxhall Company drew its water from Battersea Fields on the River Thames near one of London's biggest sewerage outlets whereas the Lambeth Company drew its water from Long Ditton an inland site of springs and wells and well out of the way from London's sewers and cesspits. Besides, it was sand

filtered! The water from the Southwark and Vauxhall Company was contaminated with human effluent. The connection between cholera mortality rates and water providers had been made but the real cause of cholera remained unknown until Robert Koch isolated the cholera bacterium some 30 years later.



Map 3 Snow's Water Service Areas Map

Spatial literacy

Spatial literacy underpins Snow's research in solving the problem of the mode of communication of cholera. The questions he asked and the way he presented his findings is a testament to Snow's ability to think spatially. Location is the essence of Snow's achievement. He integrated location data with base maps to get a sense of where things were in geographical space. He also collected attribute data from

interviews and water salinity tests which he used to tell a story. Snow identified spatial patterns and relationships in the data. Visualization of the data allowed him to communicate a simple and powerful message to an audience that wanted answers. His cholera maps served a presentational purpose on the surface but underneath they played an analytical role. He used proto-spatial analysis techniques to prove his theory. He identified a statistical correlation between service areas and mortality rates and formulated a causal explanation helping silence his critics and earn his place in medical history. Although, Snow was not alone in the use of maps to illustrate patterns and relationships in cholera mortality data, his maps were designed to persuade the scientific community and especially his pees that water played a critical role in the transmission of cholera.

Snow died of a stroke in 1858 at the age of 45. At the time his theory on the mode of communication of cholera was controversial to say the least. The miasma theory was universally accepted by those who strove for social reform. Infectious diseases like cholera were due to environmental and social causes that could be eliminated without the need of a bacteriological agent. Bad air was the cause of cholera and to suggest otherwise was inconceivable to those in power. To those like Snow who subscribed to the contagionist theory (Vandenbroucke, 1988) the facts did not add up. He performed autopsies on cholera victims and found that the lungs were in perfect condition, but the digestive tract was in bad shape. From this he concluded that cholera was ingested not inhaled.

Unfortunately, no amount of spatial analysis, logical argument or empirical evidence could convince the medical establishment and those in power to change their minds on the subject. It was to take another thirty years before Snow's work was fully appreciated. The discovery of the cholera pathogen *Vibrio cholerae* by Robert Kock in Egypt in 1883 using a high powered microscope brought an end to the debate. Cholera was caused by a bacterium and not by poison and spread from person to person through contaminated water. Modern day spatial analysis using geoprocessing tools in Geographic Information System (GIS) (Cliff & Haggett, 1988a; Dodson, 1993; Koch, 2011; Shiode, Shiode, Rod-Thatcher, Rana, & Vinten-Johansen, 2015; Wilson, 2012) and spatial statistics using R (Lindbrook, 2017) has since confirmed Snow's theory. For his work on cholera, Snow is regarded as the father of modern epidemiology. In spatial circles he is remembered for the disease mapping methods he pioneered and the spatial data analysis techniques he inspired.

Variation Theory

Variation theory provides a powerful way of understanding Snow's contribution to the aetiology of cholera. In a nutshell, variation theory provides a useful way of thinking about learning. At its core is the notion of educationally critical differences. These differences describe how learning is understood (Marton & Booth, 1997). In variation theory, educationally critical differences are used to describe a way of experiencing something in terms of critical aspects or dimension of variation of the phenomena as discerned by the learner (Pang, 2003). Marton (2015) calls these critical aspects specific keys which are necessary for learning to take place. Thus, for learning to occur "one must experience that something varies, see a difference and see it in relation to

what was earlier taken as given" (Booth, 2018). In other words, variation, discernment and simultaneity play a key role in opening up a dimension of variation around a phenomenon or aspect of a phenomenon that was once taken for granted.

To put variation theory into perspective, what Snow achieved was to open up a dimension of variation around the mode of communication of cholera. Prior to Snow's spatial analysis, books and public lectures no dimension of variation existed to account for the spread of cholera. Bad air or a 'miasma' was tacitly assumed or taken-for-granted to be the mode of communication. Miasmists believed that the disease was caused by harmful mists and vapours that arouse from London's filth, open sewers and even graveyards. The air theory appealed to the social theorists and upper classes of Victorian England. Cholera rarely visited the well to do suburbs of London: It was primarily a disease of the lower classes of London's slums. However, by offering another alternative, Snow succeeded in opening up a new dimension of variation not previously discerned in the medical literature. Not only did the water theory support the empirical evidence, but it also shone a light on the appalling public health system of the time.

London in the 1850s was not a nice place to live. The city had no sewage system no waste disposal service and no public health system. Open sewers and cesspits emptied directly into the River Thames making it the most contaminated river in the world. The Great Stink of 1858 resulting from fermenting sewage and offal in river almost caused the government to abandon Westminster. In addition, the city was overcrowded: the air quality was poor; and, most of the people lived abject squalor. The city was literally

a time-bomb waiting to explode. Against this backdrop, Snow demonstrated that London's contaminated water supply was the causal agent in cholera outbreaks. Water not air was the mode of communication of cholera.

BIBLIOGRAPHY

Booth, S. (2018). Phenomenographic Approaches to Learning *Phenomenographic Horizons* [Lecture]. Gothenburg: University of Gothenburg.

Cliff, A., & Haggett, P. (1988a). 1988: Atlas of disease distributions. Oxford, Basil Blackwell.

Cliff, A., & Haggett, P. (1988b). Atlas of the Distribution of Diseases: Analytical Approaches to Epidemiological Data. *Annals of Association of American Geographers, 8*(4), 629-630.

Dodge, M., McDerby, M., & Turner, M. (Eds.). (2008). *Geographic Visualisation Concepts, Tools and Applications*. The University of Manchester: John Wiley & Sons, Ltd.

Dodson, R. (1993). *The NCGIA Guide to Laboratory Materials-1993 (93-10)*. Retrieved from

Hajna, S., Buckeridge, D., & Hanley, J. (2015). Substantiating the impact of John Snow's contributions using data deleted during the 1936 reprinting of his original essay On the Mode of Communication of Cholera. *International Journal of Epidemiology*, 1794-1799.

Koch, T. (2000). *Cartographies of Disease: Maps, Mapping, and Medicine* (E. Press Ed.). Redlands CA.

Koch, T. (2011). Snow's Map: Cartographica Tutorial 1: ClueTrust (GBP Software, LLC).

Lindbrook, P. (2017). *R Package for Analyzing John Snow's 1854 Cholera Data*. GitHub.

Marton, F. (2015). *Necessary Conditions of Learning*. New York, NY 10017: Routledge.

Marton, F., & Booth, S. (1997). *Learning and Awareness*. Mahwah, NJ: Lawrence Erlbaum Associates.

Pang, M. (2003). Two Faces of Variation: on continuity in the phenomenographic movement. *Scandinavian Journal of Educational Research, 47*(2), 145 - 156. Retrieved from http://www.informaworld.com/10.1080/00313830308612

Shiode, N., Shiode, S., Rod-Thatcher, E., Rana, S., & Vinten-Johansen, P. (2015). The mortality rates and the space-time patterns of John Snow's cholera epidemic map. *International Journal of Health Geographics*, 14-25.

Snow, J. (1855). *On The Mode of Communication of Cholera*. London.

Tobler, W. (1971). A computer movie simulating urban growth in the Detroit region. *Economic Geography, 46*(2), 234-240.

Tufte, E. (1997). *Visual Explanations : Images and Quantities, Evidence and Narrative*. Cheshire, CT: Graphics Press. .

Vandenbroucke, J. (1988). Is 'The Causes of Cancer' as Miasma Theory for the End of the Twentieth Century? *Internatational Journal of Epidemology, 17*(4), 708-709.

Wilson, R. (2012). John Snow's famous cholera analysis data in modern GIS formats. Retrieved from http://blog.rtwilson.com/john-snows-famous-cholera-analysis-data-in-modern-gis-formats/