The power of interactive maps for communicating spatio-temporal data to health professionals

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Abstract

While more and more health-related data is being produced and published every day, few of it is being prepared in a way that would be beneficial for daily use outside the scientific realm. Interactive visualizations that can slice and condense enormous amounts of multi-dimensional data into easy-to-digest portions are a promising tool that has been under-utilized for health-related topics. Here we present two case studies for how interactive maps can be utilized to make raw health data accessible to different target audiences: i) the European Notifiable Diseases Interactive Geovisualization (ENDIG) which aims to communicate the implementation status of disease surveillance systems across the European Union to public health experts and decision makers, and ii) the Zoonotic Infection Risk in Twente-Achterhoek Map (ZIRTA map), which aims to communicate information about zoonotic diseases and their regional occurrence to general practitioners and other healthcare providers tasked with diagnosing infectious diseases on a daily basis. With these two examples, we demonstrate that relatively straight-forward interactive visualization approaches that are already widely used elsewhere can be of benefit for the realm of public health.

Introduction

With ever-increasing amounts of health-related data and information becoming available, there is a growing need for tools that make such information accessible to different target audiences. Interactive maps have become an important part of everyday life, from general purpose navigation offers like Google Maps and Openstreetmap, to specialized tools communicating detailed information wherever a static figure does not suffice. When it comes to communicating health-related facts and figures, however, the technology has not yet been utilized to its full potential in practice (Dixon *et al.*, 2022). For many diseases and conditions, relative risks depend not only on personal factors like age or occupation, but vary in space and time (Meliker and Sloan, 2011) due to environmental factors. Air pollution, for example, is a major driver for lung cancer and a series of cardio-vascular diseases (World Health Organization, 2016), while climate and climate change have been shown to strongly affect the dynamics of vector-borne infectious diseases (Caminade *et al.*, 2019). Knowing where and when disease risks are elevated can support physicians in diagnosis and treatment and guide authorities and decision makers in building strategies to alleviate those risks. Similarly, knowing which infectious diseases are or are not being monitored by health authorities is essential for researchers analysing the spatial patterns of such diseases and could prove useful for decision-making at the intergovernmental level.

Using the European Union and the Twente and Achterhoek regions, the Netherlands, as case studies, we demonstrate how an integrated system of interactive maps and dynamic figures can greatly enhance the accessibility and interpretation of complex spatio-temporal health data at any level from local to multi-national scale. We used Shiny, a R package for creating interactive web applications, to build two technology demonstrators: i) the European Notifiable Diseases Interactive Geovisualization (ENDIG): an interactive tool to visualize and explore the implementation status of governmental disease surveillance systems across the European Union; ii) the Zoonotic Infection Risk in Twente-Achterhoek (ZIRTA) Map: a prototype information system for vector-borne and zoonotic disease risk in the Twente and Achterhoek regions, aimed at physicians and healthcare professionals.

Case studies

Multi-country level

Disease surveillance systems are an integral part of national public health infrastructure that enables health care providers and clinical diagnostic laboratories to report case records to the responsible surveillance agency (Murray and Cohen, 2017). Since the turn of the century, the European Union maintains a list of infectious diseases of EU-wide concern (Commission Decision 2000/96/EC, 1999; Commission Implementing Decision (EU) 2018/945, 2018). The implementation of national disease surveillance systems for these diseases is being tracked by the European Centre for Disease Prevention and Control (ECDC), with the ultimate aim to harmonize surveillance efforts across the EU (Regulation (EU) 2022/2371 of the European Parliament and of the Council, 2022). The gathered information is being made available to the public through semi-standardized, yearly Office Open XML Workbook files (*.xlsx), but no summarizing visualizations are being provided. To fill this gap, we developed ENDIG, the *European Notifiable Disease Interactive Geovisualization* (Tjaden and Blanford, 2023), which provides a user-friendly overview of the implementation status of national disease surveillance systems for infectious diseases in the European Union. It allows the user to investigate which EU member states have implemented a disease surveillance system for a given disease, what kind of system is being used for that and how this has developed over time since 2015. ENDIG utilizes R (R Core Team, 2022) and Shiny (Chang *et al.*, 2022) to provide a user friendly web interface to the publicly available data published yearly (2015–2021) by the ECDC (Tjaden and Blanford, 2023). In a panel on the left hand side of the screen, the user can select an infectious disease from either the official EU list of "communicable diseases and related special health issues to be covered by the epidemiological surveillance network" as published in Annex 1 to the (Commission Implementing Decision (EU) 2018/945, 2018), or a set of additional diseases that is being monitored by the ECDC despite not being on the EU list. A set of radio buttons allows to focus on any of four different surveillance system characteristics: i) compulsory *vs*. voluntary reporting; ii) active *vs*. passive data collection, where in an active system the national surveillance agency is responsible for collecting the data from healthcare providers, and in a passive one the healthcare providers are responsible for reporting to the surveillance agency; iv) comprehensive *vs*. sentinel-based surveillance, where either all or only a representative sample of healthcare providers supply data, respectively; v) case-based *vs*. aggregated reporting, where either full (anonymized) case data or total number of cases are reported, respectively.

The main panel has three tabs to switch *Spatial view* and *Temporal view*, as well as an *Info* tab for additional information. The *Spatial view*'s main feature is a map of the European Union and its member states (Figure 1). Depending on the selections made in the side panel, it encodes the chosen surveillance system characteristic in shades of green and highlights in yellow countries that have not implemented a surveillance system for the selected disease yet. By default, the latest data is shown, but a slider below the main map allows to select earlier years. In *Temporal view*, the geographical view is replaced by a heatmap that uses the same color scheme to illustrate the temporal development throughout 2015–2021 (Figure 2). The static *Info* tab briefly explains the four surveillance system characteristics and links to the source code repository as well as the underlying data.

ENDIG is available online at https://github.com/Geohealth-ITC/ENDIG

Regional level

ZIRTA map, the *Zoonotic Infection Risk in Twente-Achterhoek Map* (Dutch: *Zoönotisch Infectie Risico in Twente-Achterhoek*) is an in-development interactive geovisualization of infectious disease case reports. It covers the informal regions of Twente and Achterhoek, which consists of the eastern municipalities of the provinces of Overijssel and Gelderland. It is intended as a tool for clinicians that informs them about local risk patterns of infectious diseases, including zoonoses, and raises awareness for seldomly encountered infections.

Pseudonymized laboratory test results were provided by the Laboratory for Medical Microbiology and Public Health (Labmicta), Hengelo for human infections with *Leptospira*, hantavirus, and tick-borne encephalitis virus (TBEV) throughout 2016–2023. To capture disease prevalence, we selected for positive test only: *Leptospira* positive cases were defined as those with a positive culture and/or PCR and/or serology (microscopic agglutination test (MAT) or IgM ELISA), with consistent clinical symptoms conform the national guideline (National Coordinating Body for Infectious Diseases (LCI), 2015). Hantavirus positive cases were defined as those with a positive anti-puumala virus (PUUV) IgM, or seroconversion, or significant rise in levels of anti-PUUV IgG in a follow-up blood sample, and/or positive PUUV polymerase chain reaction (PCR) test (Geeraedts *et al.*, submitted). TBEV positive cases were defined as those with detectable IgM and/or IgG in blood and/or cerebrospinal fluid samples and who fulfil the EU case definition (Weststrate *et al.*, 2017). In addition to the test result, each data point contained location (municipality name) of the individual tested, and the date of testing. Records for patients with a place of residency outside the study area were discarded, leaving a total of $n = 18$ positive cases for leptospirosis, $n = 84$ for hantavirus infection, and $n = 14$ for TBEV.

ZIRTA map utilizes R (R Core Team, 2022) and Shiny (Chang *et al.*, 2022) for interactive web app functionality with an embedded *leaflet* (Cheng *et al.*, 2023) map. The main navigation panel on the left

(Figure 3) allows the user to switch between the different pathogens. In the center of the main panel is a zoomable map displaying the case number for the chosen disease per municipality. Above the map is a dropdown menu for choosing the year as well as a slider for selecting the month of data to be shown. Below is a bar chart that shows the total case numbers across all municipalities for the individual months of the selected year as a time series, with the currently selected month highlighted in blue. A side panel on the right lists basic information about the disease along with the most common and most characteristic symptoms. A secondary tab at the top has been reserved for another page with more detailed information. Due to the early stage of development, ZIRTA map is not yet publicly available online.

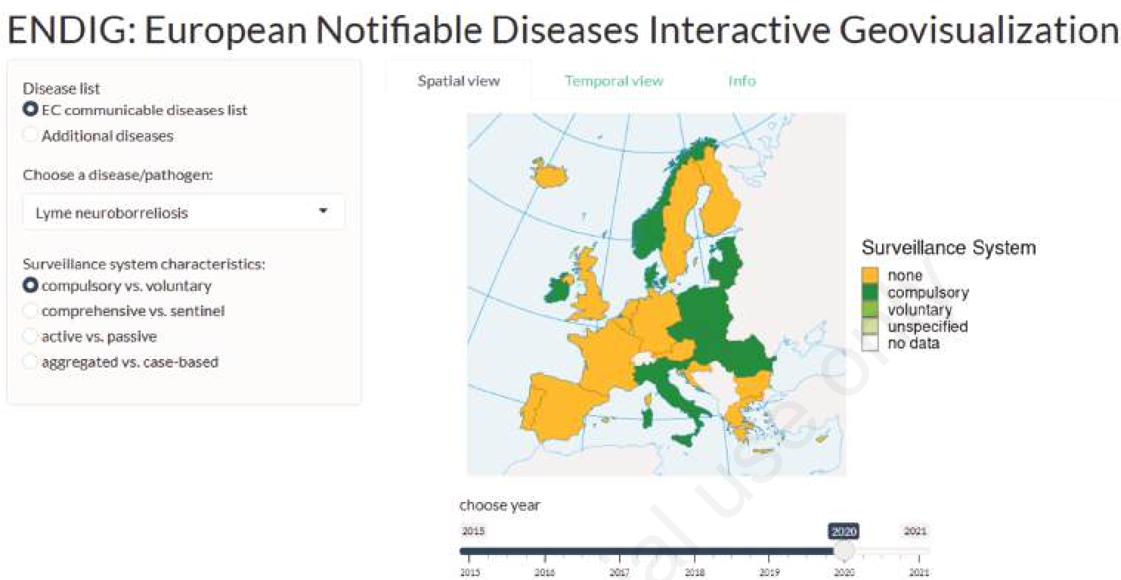

Figure 1. ENDIG in *Spatial view*, showing a map for comprehensive *vs*. sentinel-based disease surveillance systems for Lyme borreliosis in 2019.

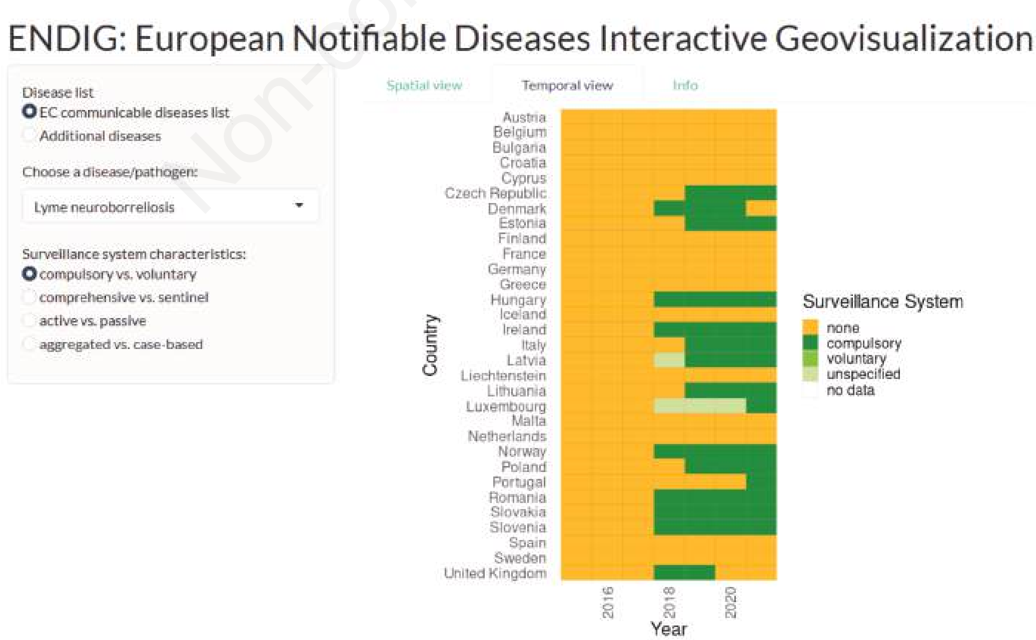

Figure 2. ENDIG in *Temporal view*, showing a time line for comprehensive vs. sentinel-based disease surveillance systems for Lyme borreliosis per country.

Results and Discussion

Our demonstrator applications shows that interactive maps have high potential for making complicated, multi-dimensional information on health-related topics. As such, they hold great promise/potential to make such complicated health-related information easily accessible for and adaptable to the needs of physicians, and the public health professionals. Especially where spatial and temporal aspects come into play simultaneously, an interactive approach can be vastly superior to any single figure (Table 1).

ENDIG fills an important gap, enhancing the ECDC suite of disease (ECDC, 2024a) and vector occurrence maps (ECDC, 2024b) by easily accessible information on how the EU member states are responding to these threats to human health. Neither the raw data tables available from the ECDC website nor the written *Annual Epidemiological Reports* (ECDC, 2020) can provide this information in a similarly accessible and comprehensive manner: At a single glance, the map in *spatial view* allows the viewer to

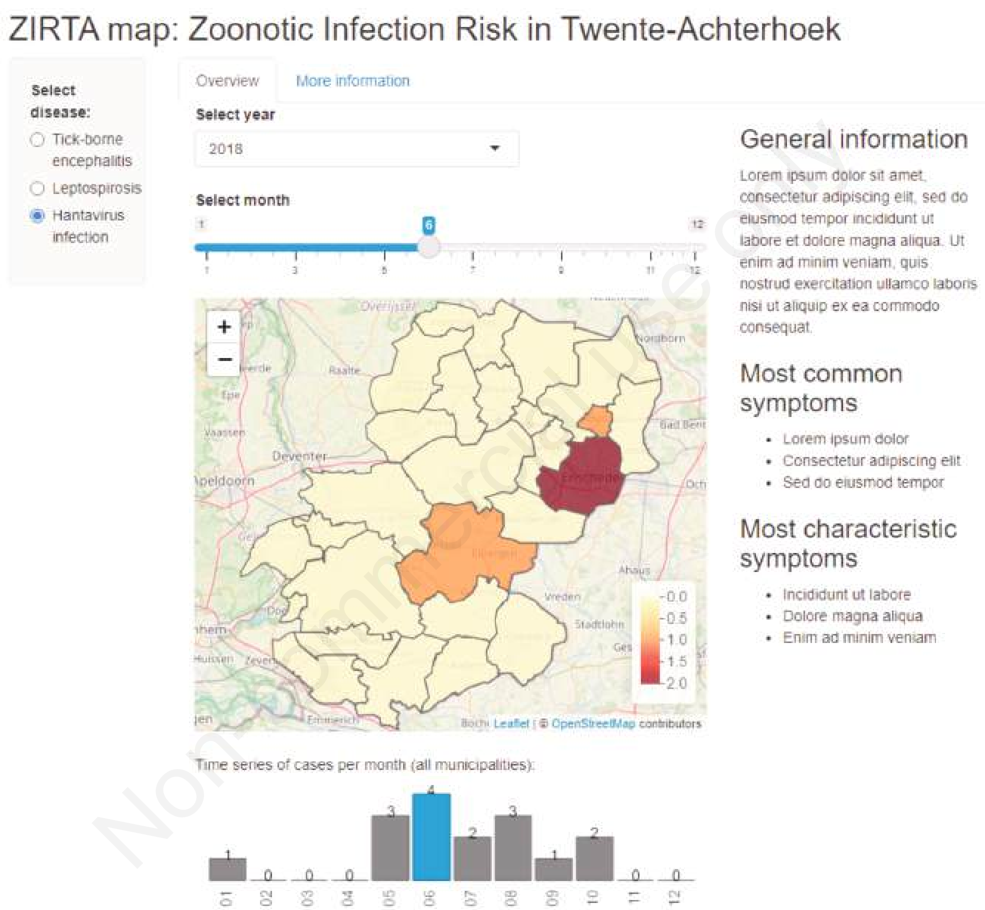

Figure 3. User interface of the ZIRTA map prototype showing disease surveillance data for hantavirus in June 2018.

Table 1. Feature summary of the two cases studies, ENDIG and ZIRTA map.

	ENDIG	ZIRTA map
Objective	Visualize implementation status of disease surveillance systems	Visualize occurrence of infectious diseases
Intended users	Researchers, decision makers, NGOs	Health authorities, healthcare providers
Diseases/pathogens covered	>60 notifiable infectious diseases	*Leptospira*, hantavirus, and tick-borne encephalitis virus
Spatial coverage	European Union, UK, Iceland, Liechtenstein and Norway	Twente and Achterhoek regions, Netherlands
Temporal coverage	2015–2021	2016–2023
Data type	Disease surveillance system types per EU country	Case numbers per municipality
Data source	ECDC “Surveillance system overview” data files.	Labmicta, Hengelo
Software used	R with Shiny	R with Shiny and Leaflet JS

assess the implementations status of disease surveillance systems for a given disease across the entire EU. The timeline plot in *temporal view* summarizes the developments in national disease surveillance system implementations across the EU. This is useful information for decision makers at the national and EU level, as well as non-governmental organizations in support of better communication of health data across the EU. For researchers investigating spatio-temoral patterns of infectious diseases, ENDIG offers easy access to crucial information about potential reporting biases.

ZIRTA map is an innovative approach in that it does not rely on regional, national, or international disease surveillance systems. Instead, anonymized disease data is supplied directly by a clinical microbiology laboratory. A bilateral agreement like this can facilitate timely data flow, reduce loss of information due to data being passed on through several institutions, and allows care providers' access to data that might otherwise remain unpublished. Once regular updates are enabled, the data can be optimized by, for instance, correcting for imported cases, ZIRTA map could provide up-to-date information on local disease transmission and raise awareness for under-diagnosed infectious diseases among health care providers. This may guide them in choosing the correct diagnostic tests, and ultimately reduce delay in proper disease management. Future iterations of ZIRTA map will preferably be co-developed with clinicians in the local hospitals and general practitioners in the region.

As recent advances in cloud computing and AI technology open up never before seen possibilities in processing and analysing ever increasing amounts of data, visualization techniques need to evolve as well. Where traditional illustration techniques would require either considerable compression of information or numerous subfigures, interactive approaches can reduce complexity while still retaining a sufficient level of detail. In increasingly data-heavy societies, translational systems like the ones proposed here will be a crucial component of evidence-based medicine and decision-making.

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