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3 Virtual Globes and Geospatial Health

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3.1 Introduction

This chapter reviews recent advances in the application of the Google Earth virtual globe (and its web pendant, Google Maps) and aims to show how it can be a useful tool as well as a strong vehicle for the dissemination of primarily health oriented research. As a result it turn, will provide public health stakeholders and decision makers with improved tools for targeting health campaigns. The specific objectives are:

1. To give examples on the current (2012) usage of virtual globes in health research and dissemination.
2. To illustrate the applicability of the technology within the context of schistosomiasis research, including the elimination programme that is currently underway in the People's Republic of China (2012).
3. To examine the full potential of virtual globe technology for surveillance, control and eventual elimination of vector-borne and other infectious diseases that depend on intermediate hosts.

These issues are discussed and a set of conclusions drawn from the examples is presented.

3.2 How It All Started

A virtual globe is essentially a three-dimensional (3-D) representation of the earth, usually based on satellite imagery, upon which various types of information with a spatial character can be superimposed. It provides the users with the ability to append their own data, to share the added data layer with other interested users and to freely move around in the virtual environment by zooming in and out, and changing the position and viewing angle. In 1998, Al Gore, then Vice President of the USA, made a speech at the California Science Center in Los Angeles, where he presented a vision of a Digital Earth, in which satellite imagery, databases and georeferenced information were

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all stored and made accessible through the Internet. Offline versions of a virtual globe had been available since the previous year through Microsoft's Encarta product. Still, Gore was very much ahead of his time, and he could imagine a near future where this information was publicly accessible for each and every one. Further, given the limits in bandwidth and home computer CPU speeds, it would be a service of libraries and museums to show the Digital Earth to the public:

> Imagine, for example, a young child going to a Digital Earth exhibit at a local museum. After donning a head-mounted display, she sees Earth as it appears from space. Using a data glove, she zooms in, using higher and higher levels of resolution, to see continents, then regions, countries, cities, and finally individual houses, trees, and other natural and man-made objects. Having found an area of the planet she is interested in exploring, she takes the equivalent of a "magic carpet ride" through a 3-D visualization of the terrain. Of course, terrain is only one of the many kinds of data with which she can interact. Using the systems' voice recognition capabilities, she is able to request information on land cover, distribution of plant and animal species, real-time weather, roads, political boundaries, and population. She can also visualize the environmental information that she and other students all over the world have collected as part of the GLOBE project. This information can be seamlessly fused with the digital map or terrain data. She can get more information on many of the objects she sees by using her data glove to click on a hyperlink. To prepare for her family's vacation to Yellowstone National Park, for example, she plans the perfect hike to the geysers, bison, and bighorn sheep that she has just read about. In fact, she can follow the trail visually from start to finish before she ever leaves the museum in her hometown.

> (Gore, 1998)

This vision is a perfect example of what virtual globes are capable of today, except that now they are pretty much accessible on most home computers with an up-to-date bandwidth connection. In fact, it was only 6 years on from Gore's speech, in 2004, before the first online virtual globe was launched by NASA (the US National Aeronautics and Space Administration). This was NASA's World Wind (see http://worldwind.arc.nasa.gov/), which was developed at the NASA Ames Research Center in Iowa. World Wind was followed in 2005 by Microsoft's MSN Virtual Earth (see Microsoft, 2005) and Google Earth. Microsoft's Virtual Earth was later rebranded as Bing Maps (available at http://www.microsoft.com/maps/). The smartphone industry is also at the forefront, Nokia having released its virtual Earth 'app', and one could speculate that it is probably only a question of time before Apple launches its version, as in 2010 it acquired the Poly9 group, an independent Canadian virtual Earth provider, followed in 2011 by acquisition of the Swedish company C3 Technologies, which creates 3-D maps with virtually no input from humans (Gurman, 2011). For a more in-depth review on the summary of current usage of virtual globes in the earth sciences, we refer the reader to Stensgaard *et al*. (2009) and Yu and Gong (2012).

It is outside the scope of this chapter to describe all the currently available virtual globe technologies or to discuss their strengths and limitations in a comprehensive and comparative manner. Instead, due to its current dominance among the virtual globe technologies, we have put the emphasis on Google Earth and its possibilities. Launched without great publicity in 2005, the prominence of Google Earth is now manifested by having been downloaded more than 1 billion times (McClendon, 2011). Perhaps Google Earth's biggest impact is the opening of the exploration of spatially explicit data to a large audience of mainly non-specialists. The application was originally called Earth Viewer and was developed by Keyhole Inc., a company acquired by Google in 2004; it was launched as a virtual globe the following year. Essentially, Google Earth maps the world by superimposing satellite raster imagery, aerial photography, vector maps and other layers, in a single and integrated tool, thus allowing users to interactively 'fly' in 3-D space, zooming in from the global to regional and local levels.

Although Google Earth is primarily aimed at the general public, and is for use mainly as a search tool, it has also attracted a large community that uses the application for a wider array of applications and purposes. Google Earth is a stand-alone application, and the user

is required to install the software on personal computers before it can be used. Google Maps, the web-based pendant to Google Earth, is a complete web page with no need to install any additional software to browse the maps displayed by the provider. Like Google Earth, Google Maps can include satellite imagery, but the view is limited to two dimensions (2-D) and it does not have Google Earth's 3-D 'tilt' feature. Google Maps does not, therefore, essentially constitute a virtual globe; nevertheless, it is included in this review as it is often used in parallel with Google Earth on research project web pages to maximize outreach by targeting a wider audience. The primary method for visualizing data in Google Earth is through the creation of Keyhole Markup Language (KML) files, which are an Extensible Markup Language (XML) notation for expressing geographic visualization and annotation. Version 2.2 of KML was released in 2008 and by then it contained most of the features that are relevant to scientific data, such as large data support and the ability to time stamp features and to create animations. KML has been declared the standard for virtual globe visualization by the Open Geospatial Consortium (OGC), and is supported by a number of virtual globe applications and geographic information system (GIS) packages.

There are numerous ways to produce KML files for Google Earth, with detailed documentation and tutorials freely available online (at http://www.google.co.uk/intl/en_uk/earth/learn/). New tools and add-ons to existing software packages are increasingly being developed to make this task as quick and easy as possible. Below, we highlight some of the most prominent new tools and add-ons:

- Users of ESRI's ArcGIS products (version 9.2 and onwards) can now export their vector and raster layers or complete map projects directly into KML file format.
- Quantum GIS, a popular free GIS software program (available at http://www.qgis.org) converts shape files to KML files and vice versa.
- Users of the Matrix Laboratory (MATLAB) platform can export results of geostatistical analysis to Google Earth by using the Google Earth toolbox.

- Online, user friendly tools, such as GPSvisualizer (see http://www.gpsvisualizer.com), convert georeferenced data files to KML format and displays it on a Yahoo or Google map. In this latter application, the source file can be either in spreadsheet format or directly imported from a handheld global positioning system (GPS) receiver.

3.3 Mapping and Visualizing Epidemiology

Epidemiology is the discipline that deals with disease patterns at the population level. In spite of focusing on exposure and outbreaks, proximal or distal, and on single or cumulative risk factors using screening and surveillance as monitoring tools, epidemiology traditionally did not have strong visual support. However, modern spatial epidemiology deals with the description and variation of the geographic distribution of a disease as a function of behavioural, demographic, environmental, genetic and socio-economic determinants and risk factors. This generally encompasses disease mapping and prediction, geographic correlation studies and cluster analysis. To understand the increasingly important role of visualization in epidemiology, we start by contemplating mapping in general, because mapping joined the visual arts long before epidemiology found it convenient to use this medium. Maps are inextricably linked to the representation of spatial relationships and the history of cartography is the history of making spatial knowledge visible.

The visualization of epidemiological data is particularly required in the current era of global change – unprecedented movement of people and trade, and globalization – in order to show on maps the present and future scenarios of epidemics. Such information is needed for the establishment of early warning systems (EWS). Areas into which certain diseases can be expected to expand have been noted for schistosomiasis in the northern part of the People's Republic of China (Yang *et al.*, 2006; Zhou *et al.*, 2008) and for malaria, leishmaniasis and dirofilariasis in northern Europe (Genchi *et al.*, 2005, 2009). Other important drivers for the (re)-emergence and spread of

vector-borne parasitic diseases include vector habitat changes (Bhunia *et al.*, 2011), pollution, resistance to pesticides and drugs and the general fallout from globalization (Harrus and Baneth, 2005). The changing distribution of previously strictly localized endemic human and livestock infections include the diseases of babesiosis, bluetongue, chikungunya, dengue, Lyme borreliosis (or Lyme disease), tick-borne encephalitis, trypanosomiasis and West Nile virus disease, and there are many more (Takken and Knols, 2007).

Aerial photography revolutionized cartography in the mid-1900s but the real breakthrough for remote sensing did not come until around 1975 when satellites equipped with photographic sensors came into wider use. Cartographers and meteorologists were the first to put these tools into civil use, while it took epidemiologists longer to appreciate the full potential of these new opportunities. Indeed, original research papers in this area did not start to appear regularly until around the late 1980s, but remote sensing, GIS and GPS are now well-known tools of the trade and few scientists working in the field can do without them. Earth-observing satellites were originally put in place for military purposes, but the information relayed back to the earth today also provides insights on climatic, ecological and anthropogenic factors related to the transmission levels and patterns of many communicable diseases (Brooker *et al.*, 2000; Rinaldi *et al.*, 2006). However, although remote sensing can clearly be of great use for epidemiological research, including disease control and elimination efforts, a bibliographic analysis reveals some risks. For example, the selection of images is often done by price and availability, resulting in poorly addressed and oversimplified data, which is sometimes not fully relevant to the research under consideration (Herbreteau *et al.*, 2006, 2007).

The study of risk factors for an infection and disease-related morbidity and mortality is an important aspect of epidemiology. The identification of causal pathways between risk factors and disease, in turn, allows the design and implementation of preventive and control measures that aim to reduce disease burdens. Infectious diseases are often considered to be 'environmental' diseases because a considerable fraction of their burden can be attributed to environmental factors (Listorti and Doumani, 2001; Prüss-Üstün and Corvalán, 2007). Hence, distribution patterns of infectious diseases are strongly associated with the spatially heterogeneous environment in which they are embedded (Woolhouse *et al.*, 1997; Brooker and Clements, 2009). Visualization of this heterogeneity, at different spatial scales, is paramount in revealing new insights into the patterns of disease. Indeed, it is only the simultaneous visualization of health data with environmental data obtained from a diversity of sources that can further our understanding of environmental health linkages and provide data for articulating new hypotheses on the distribution of diseases.

GIS are designed for this purpose and contain an increasing number of sophisticated capabilities for data display and analysis. The use of GIS in spatial epidemiology in human and animal health, and in the geospatial health sciences in general, has firmly established the technique as a useful tool for collating, exploring, visualizing and analysing health data in a spatially explicit manner (Rinaldi *et al.*, 2006; Brooker, 2007; Simoonga *et al.*, 2009; Yang *et al.*, 2012). The integration of remotely sensed environmental data into a GIS platform can deepen our understanding of the spatio-temporal dynamics of a wide range of disease systems, especially those with environmental correlates. However, high-resolution, geo-rectified imagery in a digitized format is difficult to visualize and explore without the expertise and availability of sophisticated (and often expensive) GIS software. This remains a hurdle to benefiting from the full advantages that GIS can provide for the elucidation of spatial epidemiology and geospatial health, especially in a resource-constrained developing country context.

None the less, recent advances in the development of virtual globe technology, such as Google Earth, have provided an opportunity for a cheap and accessible method for communicating epidemiological data more effectively to different stakeholders, including non-specialists. Virtual globe technologies are essentially web-based GIS tools, which bring some of the functionality of the sophisticated applied GIS to the non-specialist. Therefore,

they are suitable for the display and dissemination of research results where location and spatial variation are critical components. While virtual globe applications have limited analytical functions and are not designed to replace professional GIS software, they may be a useful complement to traditional GIS technologies and geostatistical analyses tools. In our opinion, the virtual globe technology holds a large, hitherto still under-explored potential for applications in the health sciences, especially in low- and middle-income countries.

Since around 2005, virtual globe applications in general, and Google Earth in particular, have increasingly been recognized by the scientific community as far more than just a handy map or a fun toy (Butler, 2006). They are becoming a meeting place for scientists and non-scientists alike, offering a way to connect and share data, and to exchange scientific ideas with one other. Their application pertains to a wide variety of scientific disciplines, including environmental management, biodiversity and conservation biology, urban planning, disaster management, agriculture, land use, community mapping and education, among others. For a full list see Stensgaard *et al*. (2009) and Yu and Gong (2012).

Applications of Google Earth in public health and medicine are becoming frequent. One of the earliest references made to the potential of virtual globe technology for disease mapping was highlighted by Malone (2005) in the context of vector-borne parasites. Another example worth mentioning is the scientific journal *Nature*'s use of Google Earth to track the spread of the H5N1 avian influenza virus around the globe (Butler, 2006). A further example convincingly showing the operational usage of Google Earth in public health was its use to track a polio virus outbreak down the Congo River (Kamadjeu, 2009).

3.4   Health Projects

Health projects, whether driven by a specific research question or public health initiatives, have increasingly applied virtual globes as a powerful tool for monitoring and presenting health-related data. In other words, in addition to its increasingly common use in epidemiological prospective studies, virtual globe technology and Google Earth have also been used retrospectively by creating and publishing Google Earth KML files of key findings to supplement scientific publications and to broaden the dissemination of results. We do not list all the current health projects that use this technology, as the number of different projects is not stable, but brief details of four of these are given below (for a recent list, see Stensgaard *et al*., 2009 and Duhl *et al*., 2011).

- *Disease outbreak and real time surveillance*. Butler (2006) won the Association of Online Publishers (AOP) Use of the New Digital Platform Award 2006 for tracking the spread of the H5N1 avian influenza virus around the globe. This Google Earth presentation compiles data on outbreaks of avian flu in birds from 2003 onwards and on confirmed human cases of infection, as well as other relevant spatial data layers, in order to map cases and outbreaks by location and time, with links to relevant web resources from the Food and Agriculture Organization (FAO) of the United Nations, the World Health Organization (WHO) and other organizations (Butler, 2006). This example demonstrates the potential of so-called 'mashups', a term originally used to describe the mixing together of musical tracks, but now referring to web sites that weave data from different sources into a new service (Boulos *et al*., 2006). Further examples can be found at the Google Earth Outreach initiative web site (http://earth.google.com/outreach/index.html), which contains a continuously updated online overview of health-related showcases.

- *Global warming and disease*. This project was a collaboration between Google and a group of epidemiologists looking at the impact of climate change on vector-borne diseases. Based on the findings from several separate studies (Hales *et al*., 2002; Tanser *et al*., 2003; Ezzati *et al*., 2004; Ebi *et al*., 2005), the different research groups created a KML animation named 'GlobalWarmingDisease.kml' (Adams, 2008); this shows the projections for the

changes in the global transmission of dengue and malaria in Africa (see Fig. 3.1).

- A third project, *HealthMap*, has been carried forward by a team of researchers, epidemiologists and software developers based at Children's Hospital Boston. This database project was initiated in 2006, and has become a global leader in utilizing online informal sources for disease outbreak monitoring and real time surveillance of emerging public health threats (HealthMap, 2012). Since its inception, the project has now grown and branched out into several sub-projects from flu surveillance to the HN1 influenza A (swine flu) outbreak, as well as cholera cases reported on Haiti and African swine fever (AFS) outbreaks. Details of these are available on the HealthMap web site (healthmap.org/projects/).

- Imperial College London, on its Spatialepidemiology.net web site (http://www.spatialepidemiology.net/), has created interesting mashups combining genetic and epidemiological data on pathogenic microorganisms. This site not only provides a Google Earth map-based interface for the display and analysis of epidemiological data, but also allows users to create their own maps easily through the Google Maps application programming interface (API).
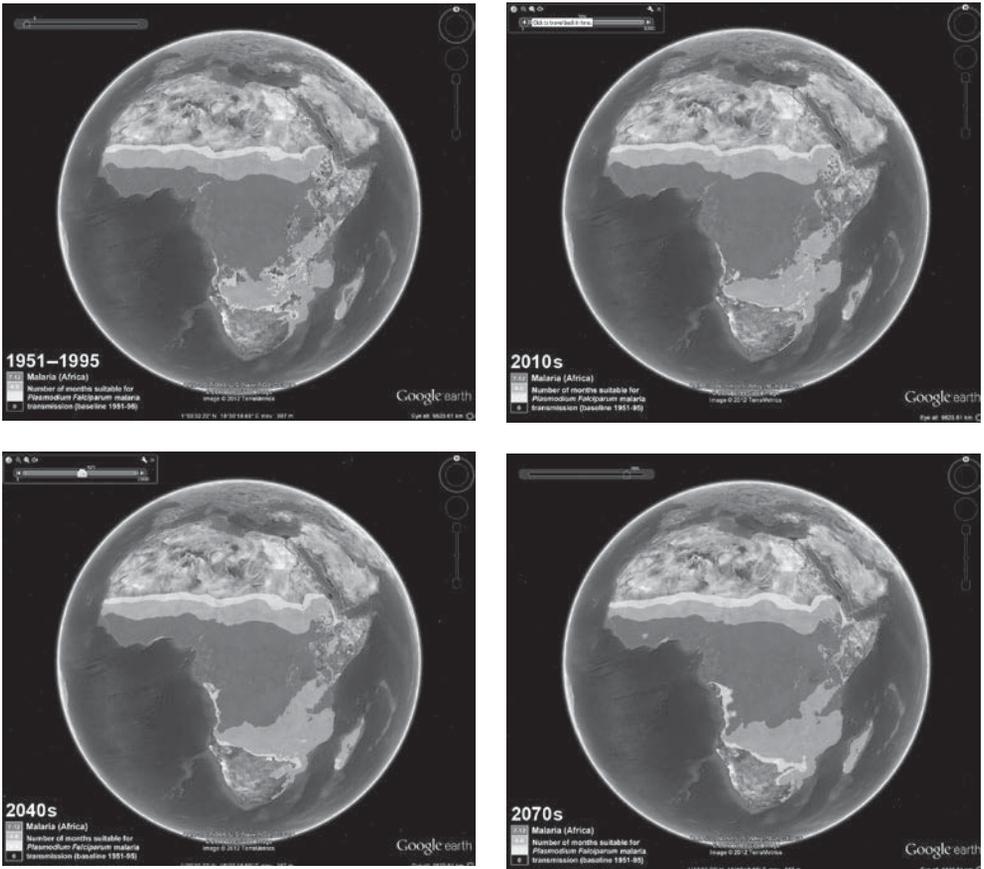
Fig. 3.1. A KML file of Google Earth layers showing the change in spread of malaria as a result of global warming (http://services.google.com/dotorg/kml/worldhealthday2008/GlobalWarmingDisease.kml). The source data comes from the MARA (Mapping Malaria Risk in Africa) project collaboration (Tanser *et al.*, 2003).

The three subsections below discuss three applications of Google Earth to schistosomiasis projects.

3.4.1 Usage of Google Earth in the CONTRAST research project

Google Earth and Google Maps were applied within the framework of a 4-year European Union (EU) funded project under the acronym of CONTRAST (a multidisciplinary alliance to optimize schistosomiasis control and transmission surveillance in sub-Saharan Africa), for which details are available at http://www.eu-contrast.eu/. This EU funded project ran from late 2006 to late 2010 and aimed at building a multidisciplinary research platform to better understand which interventions should be used to control the snail-borne parasitic disease schistosomiasis and how to tailor interventions at the local level. The morbidity of schistosomiasis is predominantly controlled by preventive chemotherapy campaigns (using the anti-schistosomal – anthelminthic – drug praziquantel) (WHO, 2006; Hotez et al., 2007). However, in order to achieve sustained success in reducing transmission and ultimately reaching the goal of elimination, a thorough consideration of the environmental components is essential, because the disease is completely dependent on its freshwater-dwelling intermediate host snail (Stothard et al., 2009; Utzinger et al., 2011a).

A key feature of the CONTRAST project was the highly interdisciplinary team efforts, consisting of a strong research node network across Africa, which brought together key skills and expertise to generate new knowledge on molecular, biological, environmental and socioeconomic risk factors relating to schistosomiasis in different parts of the continent. These nodes worked on establishing innovative molecular tools to characterize both intermediate host snails (Standley et al., 2011) and schistosome parasites (Kane et al., 2011), and the potential genetic consequences of large-scale administration of anthelmintic drugs (Norton et al., 2010). This work has defined the importance of host–parasite dynamics across different eco-epidemiological

settings and resulted in the development of new spatial models for disease risk mapping and prediction (Schur et al., 2011b; Stensgaard et al., 2011). An additional aim of CONTRAST was to encourage and assess novel, local control interventions using a social science approach, while ensuring widespread dispersal of and access to information. Virtual globe technology lends itself particularly well to the activities within research projects such as CONTRAST that are concerned with the spatial epidemiology for risk mapping and prediction at non-sampled locations (Hürlimann et al., 2011; Schur et al., 2011a,b). Google's virtual globe technologies were used for a variety of purposes, ranging from partner communication, data visualization and validation to web-based dissemination of project research and key results.

The conceptual diagram in Fig. 3.2 illustrates where and how Google Earth and Google Maps were used in the project, project work flows and stages. The overall communication and assembly of project-related data took place via the CONTRAST web page (stage 1), where Google Earth and Google Maps were used to communicate in a spatially explicit manner. New data collected by the project partners during epidemiological and malacological surveys were entered online using a standardized format managed by the FireFlower data management system (http://www.fireflower.ca). Historical data on schistosome parasites and intermediate host snails for all of sub-Saharan Africa are continuously being collated and digitized using a systematic approach to review extant literature and managed in a relational database with direct KML export capabilities (stage 2 – see Hürlimann et al. (2011) for details). Here, the Google Earth display of data can be used for data location, georeferencing, validation and gap identification. The development of predictive models of disease distribution takes place via advanced spatial and geostatistical analysis (stage 3). As Google Earth has no analytical capabilities, this process essentially occurs through statistical software packages (e.g. STATA, from the Stata Corporation, College Station, Texas, version 9.2; WinBUGS, from Imperial College and the Medical Research Council, London, UK, version 1.4.2;
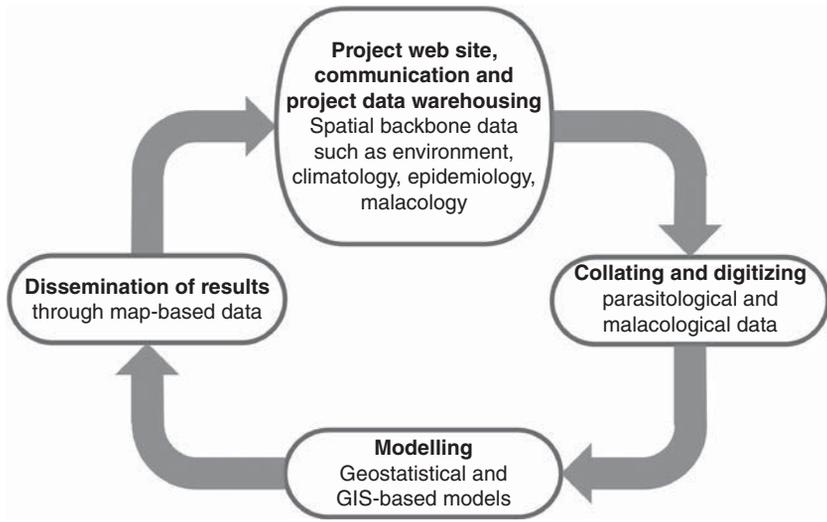
Fig. 3.2. Conceptual diagram showing the work-flow and stages in the EU-funded CONTRAST project (an alliance for optimizing schistosomiasis control and transmission surveillance in sub-Saharan Africa), relating specifically to spatial epidemiology for schistosomiasis risk mapping and prediction at non-sampled locations. Google Earth's virtual globe technologies are applied in all but the modelling stage.

and R, see http://www.R-project.org), as well as more conventional GIS packages. Finally, in addition to the common dissemination of results through scientific literature, models and other research results are illustrated via Google Earth (stage 4). The extensive public interest in such visualizations makes the scientific information widely accessible to general users. To underscore this issue, the Hürlimann *et al.* paper, published in December 2011, was accessed over 5400 times by mid-June 2013. Also of note, personal data and results can be combined with other spatial data and thereby stimulate scientific debate and the articulation of new research questions and hypotheses.

Data visualization is also useful for decision support, particularly in the spatial targeting of disease control measures, but also for the identification of knowledge gaps and the stimulation of further data collection. Figure 3.3 shows a screen shot of one of the Senegalese field sites – Temeye, on the lake Lac de Guiers – where schistosomiasis transmission is widespread.

3.4.2 Developing a digital, interactive atlas of the distribution of schistosomiasis and intermediate host snails

Another example of the use of Google Earth in a schistosomiasis project pertains to its role in efforts to develop a digital, interactive atlas of the distribution of schistosomiasis and its intermediate host snails (Hürlimann *et al.*, 2011). This is thus a logical continuation of the initial efforts made by the University of Bordeaux (France) and WHO in the 1980s, which resulted in the publication of the first global, printed atlas of schistosomiasis (Doumenge *et al.*, 1987). However, because this atlas appeared just before the 'age of the Internet', it cannot be updated continuously as new data become available.

Since the inception of the CONTRAST project in October 2006, considerable efforts have gone into digitizing and georeferencing historical records of schistosomiasis prevalence data and intermediate host snail species. These data are being assembled in

Fig. 3.3. A screenshot displaying the use of Google Maps as applied for presenting a field site (Temeye, Senegal) in the CONTRAST project.

the open source MySQL relational database management system, and are continuously updated. As of 1 June 2012, the database consists of more than 12,000 georeferenced locations with associated parasite prevalence data, along with information on the distribution of the intermediate host snail species associated with the transmission of schistosomiasis. Geocoding, the process of converting text descriptions of locations to computer-readable geographic locations (e.g. latitudes and longitudes, see Chapter 4), is carried out using gazetteers such as the BioGeo-Mancer (http://www.biogeomancer.org/ https://sites.google.com/site/biogeomancerworkbench/) (Guralnick *et al.*, 2006).

The CONTRAST database, with an initial focus on schistosomiasis in Africa, has been extended geographically and in terms of its

disease portfolio to include other neglected tropical diseases (NTDs). Indeed, towards the end of 2011, the database has been made publicly available under the name of the GNTD Database 'gntd.org' (Fig. 3.4). Future plans are to utilize Google's virtual globe technology as part of the database interface. An advantage of this approach is that any person working with the database can directly export any chosen data selection directly from the database to a KML file for instant viewing in Google Earth. The files can be emailed to colleagues (who may have no knowledge of, or access to, GIS), and then simply be 'dragged and dropped' by the recipient on to their own desktop Google Earth display, where the layer is immediately draped over the Google Earth landscape. This simple and instant mapping in Google Earth
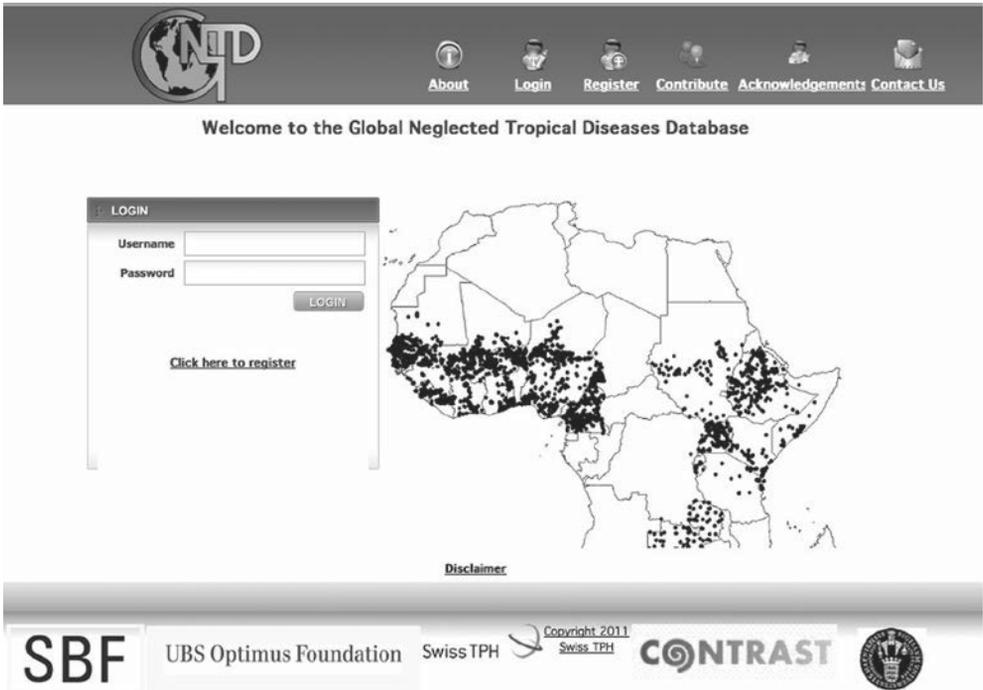
Fig. 3.4. A screenshot of the front page of the Global Neglected Tropical Diseases (GNTD) Database (available at http://www.gntd.org).

serves several purposes. It has made it possible to quickly identify spatial data gaps and it has been helpful in identifying areas where further epidemiological and malacological surveys are warranted. It has also proven instrumental in validating the global position of the thousands of localities (small rural settlements, towns, etc.) that have been retrospectively georeferenced; partners in various geographic regions can quickly identify geocoding errors, and hence assist with improving the precision of the geographic coordinates.

3.4.3 Going from science to operational public health management: a Web GIS platform to monitor and forecast schistosomiasis in the People's Republic of China

The Internet has undeniably played an integral part in giving scientists and decision makers access to near real time data. The presentation of data based on interactive, computer-generated map applications represents a straightforward way of visualizing large numbers of data sets in a geographic context. In the People's Republic of China, combining spatial data from Google Earth with a GIS package has developed a basic Web GIS framework for the rapid assessment of the risk for schistosomiasis (see Fig. 3.5). This framework provides dynamic information on an important endemic disease in near real time and has the added function of an EWS as it can quickly locate high-risk areas. The system retrieves all-important data needed as well as providing detailed and up-to-date information on the performance of the control programme for the disease. In this way, the epidemiological status of schistosomiasis can be shared in near real time, not only with the individual researchers around the country who are at work extending the evidence base but, most importantly, with decision makers and disease control managers.

The Chinese Web GIS platform includes remotely sensed data and GIS analysis as well
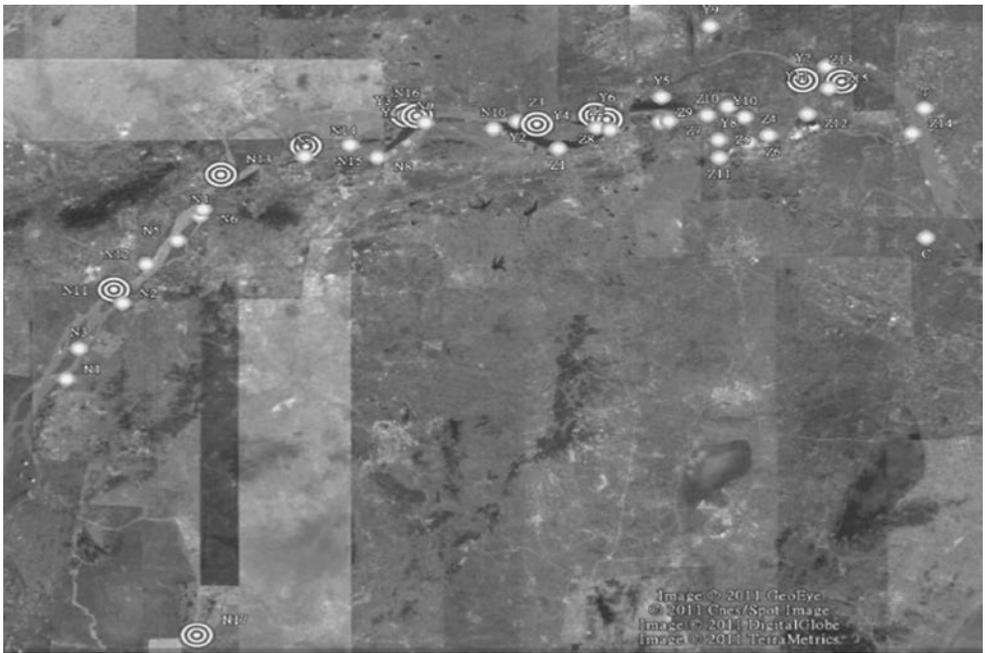
Fig. 3.5. Chinese Web GIS showing the 45 surveillance sites for schistosomiasis monitoring in Jiangsu Province. The sites are located approximately 10 km from each other along both banks of the lower reaches of the Yangtze River. The surveillance period was May–September for 3 years (2009–2011), and the surveys were done each month at high tides. Target (bull's eye) symbols indicate positive sites.

as visualization of the distribution of schistosomiasis and intermediate host snail habitats. The latter information is not only provided by searches using Google Earth but is also collected through field surveys. Furthermore, it includes advanced risk forecasts based on data stored in the server processed by spatiotemporal modelling, e.g. the WinBUGS (Bayesian inference Using Gibbs Sampling) programme (available at http://www.mrc-bsu.cam.ac.uk/bugs/).

The available layers of the Web GIS platform include information on:

- the current endemic status of schistosomiasis
- prevalence in humans and livestock (most importantly water buffalo)
- snail distribution, snail density and percentage of infected snails
- control measures implemented
- high-risk regions

Users can request maps by e-mail or download them in KML format for importation into their own GIS software packages. They can also obtain information about historic endemic situations and field information in the form of pictures or videos; the system permits results in the form of annotated maps to be generated and printed as well.

The Web GIS uses common industry standards, including widely accepted data descriptions and communication protocols to facilitate interoperability and portability, thereby permitting communication and data transfer between units running on different platforms and using different technologies, e.g. the different versions of Internet Explorer and Firefox, as well as the Linux-based operating systems and MacOS. The components that make up the platform were chosen so they could be bundled together without having to write specific computer programs. The database was designed with consideration to the environmental parameters influencing the prevalence of schistosomiasis in humans, reservoir animals and the intermediate host snail, as well as the risk for outbreaks due

to the continuous population flux between rural and urban areas – the importance of which for the transmission of various diseases has been pointed out by many authors (Engels *et al.*, 2002; Taylor, 2008; Wang *et al.*, 2008).

The design of the platform is capable of providing analyses based on remotely sensed data and GIS applications. Active control programmes are constantly generating updated information and the platform should be capable of following and incorporating these developments in near real time, the necessity of which has been pointed out many times (Taylor, 2008; Wang *et al.*, 2008, 2009; Zhou *et al.*, 2008). Ongoing field operations require constant guidance and the platform must be ready to respond to queries on the effectiveness of a particular intervention approach in certain settings, or the feasibility of interventions in relation to the resources available, i.e. when and where to intervene and how to identify and locate high-risk areas. The experience of using the platform is encouraging and it has the potential to improve present support systems and strengthen schistosomiasis control activities, in particular for surveillance EWS and current efforts towards the elimination of schistosomiasis. What makes this development particularly interesting is that the approach chosen can be used for the validation and surveillance of any disease, and even outside the area of communicable infections.

The combination of GIS, remote sensing and Google Earth technologies offers new opportunities for the rapid assessment of endemic areas, provision of reliable estimates of populations at risk, prediction of disease distributions in remote areas that lack baseline data and guidance of intervention strategies so that scarce resources are allocated in the most cost-effective manner possible (Yang *et al.*, 2005; Chen *et al.*, 2007; Zhou *et al.*, 2009). The Web GIS approach makes it possible to analyse complex geospatial data and communicate them in a user-friendly graphical format, thus solving the problem of presenting and explaining the epidemiological situation for decision makers and the general public in a case-by-case manner (Theseira, 2002; Croner, 2003; Kamadjeu and Tolentino, 2006; Maclachlan *et al.*, 2007; Syed-Mohamad, 2009).

As the technology for Web GIS development becomes more and more readily available, including access to software systems for data management, geographic data visualization through the Internet (e.g. MapServer), geographic data analysis (e.g. ArcGIS), spatial statistics and Internet server management (e.g. Apache, http://httpd.apache.org/ABOUT_APACHE.html), then general purpose applications will become more common. The XML-based standard Geography Markup Language (GML) is becoming the world standard language for encoding geographic features and geoprocessing service requests (Boulos, 2004). By comparison, many agencies, particularly in the USA, have an extensive Web GIS presence presenting a multitude of digital geospatial data from various areas, e.g. improving hospital bed availability in community health and bioterrorism surveillance services (Boulos, 2004), and the information on West Nile Virus at the United States Geological Survey (USGS) web site (http://diseasemaps.usgs.gov/wnv_us_human.html).

The challenge for real time surveillance platforms is to adapt technologically advanced and costly concepts for disease management to resource-poor environments by developing low-cost tools and solutions (Hrster and Wilbois, 2007; Choo, 2009). Alhough satellite imagery has been available for over half a century, its broader use was limited until the Landsat programme was initiated in 1972 (http://landsat.gsfc.nasa.gov/). Due to cost and quality issues, though, the satellite technology has remained in the industrial world and spread only slowly to the developing countries. However, the past few years have seen this 'monopoly' give way to a more global use, at least for the satellite imagery produced.

3.5 A New Generation of 'vHealth' Papers

The old adage 'A picture is worth a thousand words' was discussed at a symposium held during the 60th Annual Meeting of the American Society of Tropical Medicine and Hygiene in Philadelphia in December 2011 in connection with new ways of visualizing health data using

geospatial tools, including remote sensing, GIS and Google Earth (Utzinger *et al.*, 2011b). Ideas discussed and further consolidated during this symposium were subsequently translated into the concept of 'vHealth' papers ('v' standing for visualization). In an editorial published in the May 2012 issue of the journal *Geospatial Health*, the launch of vHealth papers is featured (Bergquist and Tanner, 2012). The editorial goes hand in hand with three examples, giving a flavour of the potential of geospatial tools, including virtual globes, for visualizing complex public health issues (see Fig. 3.6) (Krieger *et al.*, 2012; Maire *et al.*, 2012; Winkler *et al.*, 2012). The key feature of these vHealth papers is that they contain a link to a video, which can be readily downloaded free of charge or directly viewed on any personal computer connected to the Internet. Importantly, two of these vHealth papers use Google Earth applications. These are briefly summarized here (Krieger *et al.*, 2012; Maire *et al.*, 2012).

Krieger *et al.* (2012) pursued numerous integrated impact assessments of projects with particular emphasis on the health impacts on local communities of large-scale industrial projects in the developing world. These impact assessments usually result in reports of several hundreds of pages, with numerous technical appendices that are difficult to access by non-specialists. In an effort to bring the key findings across to senior management in a more digestible format, the key essence of such impact assessments is captured in short video clips that contain spatially explicit data. For example, the predicted environmental and health risks and accompanying mitigation strategies for a uranium mine in Tajikistan are highlighted. Using Google Earth, the viewer of a 17 min video clip is zoomed from the globe right into the heart of the uranium mine near the town of Adrasman in northern Tajikistan. Aided by 3-D 'fly-through' visuals and sophisticated video sequence generation overlaid on project-specific satellite imagery and GIS products, and assisted by object-based imagery analysis, segmentation and land feature classification, the viewer embarks on a virtual tour of the mining site, quite similar to that predicted by Al Gore in the 1990s. While the current video is designated for senior management of the international finance cooperation and development banks, it can be readily adapted to other stakeholders, including non-literate communities that will be affected by the project.

Maire *et al.* (2012) provided an overview of the development of the Health Resources Allocation Model (HRAM) dating back to the late 1980s, in which they explain how this eLearning tool has been widely and successfully used by health cadres and scientists. Indeed, the HRAM is a powerful tool for introducing the basic concepts of rational district-based health planning and systems thinking under resources constraints. The model was initially developed as a simple DOS program with data from the Kilombero district in Tanzania. It allows the evaluation of resource allocation strategies in relation to key outcome measures (e.g. coverage with insecticide-treated nets, vaccination among under 5 year old children, equity of services achieved and number of deaths and disability-adjusted life years (DALYs) averted by to specific health interventions. Most importantly, the model takes into account geographic and demographic characteristics and the health seeking behaviour of populations. Google Earth is utilized as the platform for spatial data display. Furthermore, HRAM can be extended to other social–ecological and health systems settings in developing countries.

3.6 Discussion and Conclusion

The ease, efficiency and speed of data communication and analyses are paramount to, and characteristic of, any mature science. The key strengths of virtual globe applications are their relatively simple, intuitive nature and ability to incorporate new data in a straightforward manner. GIS software is already an important tool for understanding spatial and temporal factors in a wide range of disciplines, increasingly so in the geospatial health sciences, which investigate links between diseases and the multidimensional environments in which they occur. However, commercial GIS tools have traditionally been an expensive and complex solution, especially in the developing world. They are often not mutually compatible,
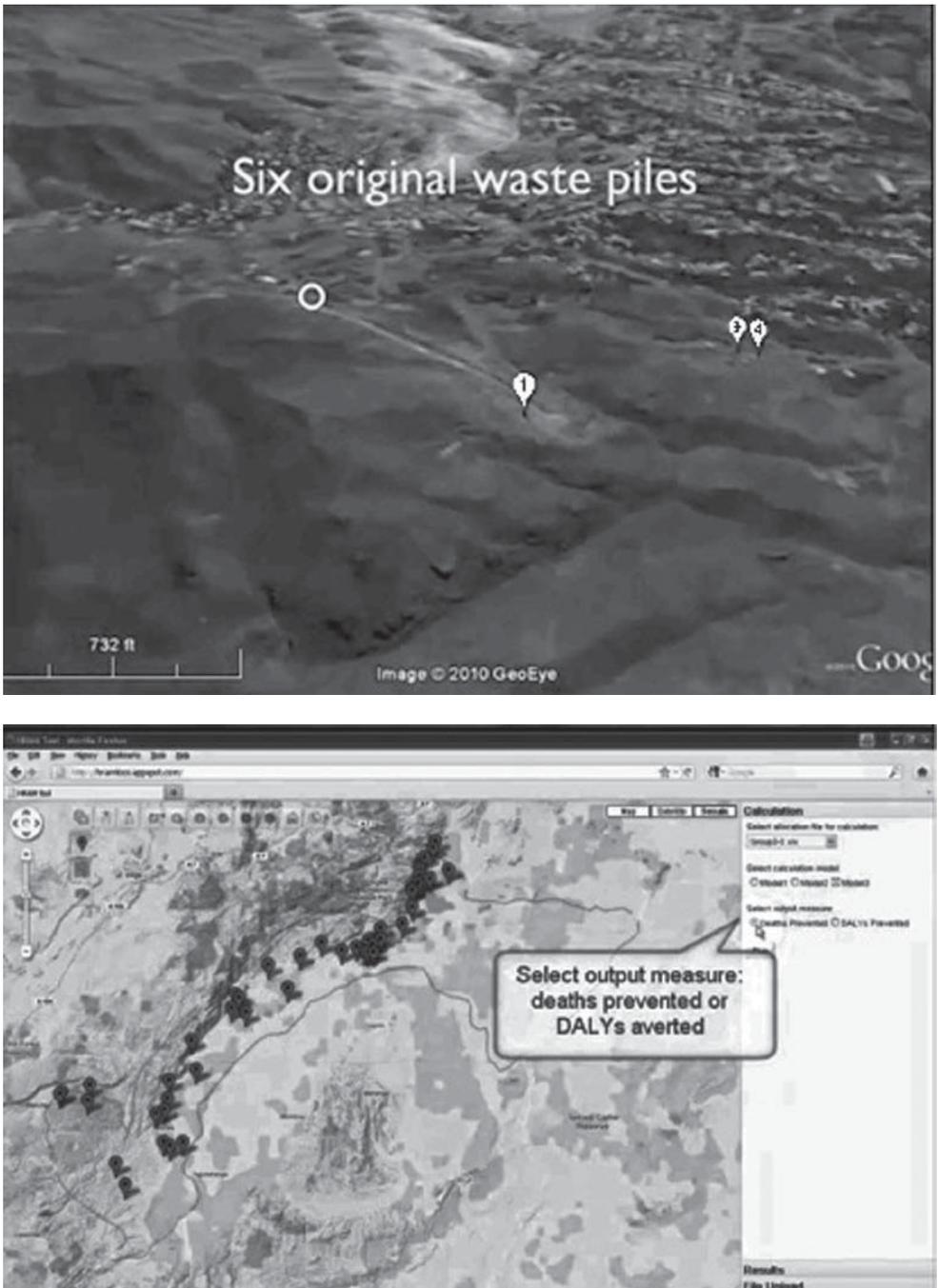
Fig. 3.6. Stills from the 'vHealth' papers in the journal *Geospatial Health* by Krieger *et al.* (2012) and Maire *et al.* (2012). At the top is a 3-D fly-in showing the location of waste piles – a novel way of enhancing environmental impact assessment through visualization. At the bottom is an example of how Google Maps layers are used in the Health Resources Allocation Model (HRAM), an eLearning tool (DALY, disability-adjusted life years).

making it difficult to combine data from different sources in a smooth manner.

Google Earth and other virtual globe applications offer researchers a simpler alternative to GIS software and we envisage that this will lead to increased data sharing (beyond static images), while enabling the implementation of a new and exciting science. Thus, Google Earth has the potential to make mapping accessible to a new set of public health users, including the developing world. The availability and quality of satellite imagery, combined with features such as KML or image overlay, provide a flexible yet powerful platform that set it apart from traditional mapping tools. It should be emphasized, though, that virtual globe applications are engineered to do only a small portion of what a full GIS technology does, and should be viewed as a complement to, rather than a full replacement of, more sophisticated GIS technologies. The following points are offered for discussion of some of the merits and limitations of Google Earth as compared with other virtual globe technologies and GIS.

First and foremost, Google Earth allows easy simultaneous visualization of point data together with many of types of auxiliary environmental data, which makes it well suited for the 'exploratory' phases of scientific work. Users can upload their own georeferenced data (in point, polygon and raster format) and share it with selected users or, alternatively, with the whole impressive network that is the Google Earth community. Although Google Earth does not offer traditional GIS functionality, it can also be used to add content, such as points or lines, to the existing maps, and to measure areas and distances, derive coordinates and ultimately load GPS data.

Secondly, for web-based data sharing, the data is readily located on Internet servers. This means that users do not have to download or install any data locally – although the need to access the Internet (e.g. to capture satellite images of areas of interest) is a limitation that will impede the use of Google Earth for this purpose in some parts of the world.

Thirdly, the base maps in Google Earth (remote sensing images, roads, administrative units, topography, etc.) are extensive and, above all, are frequently updated and constantly improving in quality. Though still far from suitable for all kinds of epidemiological studies, this brings new promise for the improved use of remote sensing applied to epidemiology, which hitherto has been criticized for not fulfilling its promises (Herbreteau *et al.*, 2007). A limitation is that non-urban areas in the developing parts of the world still suffer from poor coverage of high-resolution satellite imagery. This is a limitation that is a particular problem for local studies of many diseases, including schistosomiasis and other NTDs, as well as malaria. Another limitation with acquiring high-resolution imagery through Google Earth is that the exact acquisition date of the image cannot be chosen, which makes it less than perfect for analysis purposes (Monkkonen, 2008; Kamadjeu, 2009). Although Google Earth, with its version 5, has opened the possibility for accessing (and presenting) historical imagery (Hanke, 2009), there is no way to select the date of image acquisition. Especially in regions with strong climatic seasonality, such as the Sahel region of Africa, this poses a problem. If landscape features are to be monitored over time, it is important to retrieve data from the same time of the year.

An important strength of Google Earth is that it uses a single coordinate system, i.e. the world geodetic system (WGS-84) and that the geodata are visualized using a 3-D model rather than a projected 2-D system. This means that the user avoids having to deal with the complexity of understanding and merging maps and layers from different projection systems. The fact that more and more people and organizations are now producing KML versions of their spatial data (as opposed to other spatial data formats that require different types of GIS software) has made it easy for scientists, and the general public alike, to quickly prepare mashups and explore data obtained by different research groups. The use of Google Earth and Google Maps in the CONTRAST project, which is also generally applicable to other research projects with geospatial health components, can be summarized in a few overall categories such as:

- visualization
- communication
- data exploration (e.g. the identification of spatial and temporal disease clustering)

- validation
- dissemination of research results for a wider audience
- support for decision making

A remaining problem, though, is how to attain the proper geocoding of disease-related data, not least for the vectors and the intermediate hosts carrying the infectious agents; this still hinders the full potential of virtual globe applications for these purposes. Failure to include spatial information may eliminate potentially highly productive routes to analysis, including those not yet foreseen. But these data are frequently inadequate or absent, and this remains one of the main obstacles for the direct mapping of, for instance, vector-borne diseases and the exploration of their relationships with the heterogeneous environment in which they exist. Other important issues, not dealt with in this chapter, pertain to the ethics of displaying traceable health information in public space and concerns with confidentiality of the data (Curtis *et al.*, 2006; Mak, 2012). According to some, the type of visualization exemplified by the virtual globe crosses several ethical thresholds in communicating scientific and environmental information, and participatory uses of virtual globes by experts and laypeople carry both benefits and risks (Sheppard and Cizek, 2009). Thus, while the appeal of these techniques is evident, with unprecedented

opportunities for public access to data and collaborative engagement over the web there are, none the less, several important ethical aspects that need to be considered before applying these techniques in areas of public interest, such as planning and policy making. At present, Google Earth appears to be primarily used as a geobrowser for exploring spatially referenced data. However, its functionality can be integrated with various analytical tools for spatial analysis (e.g. GIS and open-source statistical packages such as R; Bivand, 2006), while facilitating the sharing of spatially referenced data between international research groups and agencies (Wood *et al.*, 2007).

We hope that this chapter will stimulate further exploration of virtual globe applications for spatial epidemiologists, and that this could also introduce the broader research community to the potential of recording and producing accessible spatial data in appropriate formats. We continue to use Google Earth and Google Maps as an integral part of the next phase of the CONTRAST project and we invite readers to check the project's web site, as well as the web sites of the many other research projects mentioned in this chapter, to witness how virtual globe applications can be used for the display and sharing of data and research relevant to the management and control of vector-borne and other environmental diseases.

References

Adams, C. (2008) Global warming heats up infectious diseases. The Official google.org blog, Monday 4/07/2008 08:32:00 AM. Available at: http://blog.google.org/2008/04/global-warming-heats-up-infectious.html (accessed 13 March 2013).

Bergquist, R. and Tanner, M. (2012) Visual approaches for strengthening research, science communication and public health impact, *Geospatial Health* 6, 155–156.

Bhunia, G.S., Kesari, S., Chatterjee, N., Pal, D.K., Kumar, V., Ranjan, A. and Das, P. (2011) Incidence of visceral leishmaniasis in the Vaishali district of Bihar, India: spatial patterns and role of inland water bodies. *Geospatial Health* 5, 205–215.

Bivand, R. (2006) Implementing spatial data analysis software tools in R. *Geographical Analysis* 38, 23–40.

Boulos, M. (2004) Towards evidence-based, GIS-driven national spatial health information infrastructure and surveillance services in the United Kingdom. *International Journal of Health Geographics* 3:1.

Boulos, M.N.K., Scotch, M., Cheung, K.-H. and Burden, D. (2006) Web GIS in practice VI: a demo playlist of geo-mashups for public health neogeographers. *International Journal of Health Geographics* 7:38.

Brooker, S. (2007) Spatial epidemiology of human schistosomiasis in Africa: risk models, transmission dynamics and control. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 101, 1–8.

Brooker, S. and Clements, A.C. (2009) Spatial heterogeneity of parasite co-infection: determinants and geosta-
    tistical prediction at regional scales. *International Journal for Parasitology* 39, 591–597.
Brooker, S., Rowlands, M., Haller, L., Savioli, L. and Bundy, D.A.P. (2000) Towards an atlas of human helminth
    infection in sub-Saharan Africa: the use of geographical information systems (GIS). *Parasitology Today*
    16, 303–307.
Butler, D. (2006) Mashups mix data into global service. *Nature* 439, 6–7.
Chen, Z., *et al.* (2007) Strategy formulation for schistosomiasis japonica control in different environmental
    settings supported by spatial analysis: a case study from China. *Geospatial Health* 1, 223–231.
Choo, C.W. (2009) Information use and early warning effectiveness: perspectives and prospects. *Journal of the
    American Society for Information Science and Technology* 60, 1071–1082.
Croner, C.M. (2003) Public health, GIS and the Internet. *Annual Review of Public Health* 24, 57–82.
Curtis, A.J., Mills, J.W. and Leitner, M. (2006) Spatial confidentiality and GIS: re-engineering mortality locations
    from published maps about Hurricane Katrina. *International Journal of Health Geographics* 5:44.
Doumenge, J.P., Mott, K.E., Cheung, C., Villenave, D. and Chapuis, O. (1987) *Atlas of the Global Distribution
    of Schistosomiasis*. Presses Universitaires de Bordeaux, Bordeaux, France.
Duhl, T.R., Guenther, A. and Helmig, D. (2011) Estimating urban vegetation cover fraction using Google
    Earth® images. *Journal of Land Use Science* 6, 1–19.
Ebi, K.L., Hartman, J., Chan, N., McConnell, J., Schlesinger, M. and Weyant, J. (2005) Climate suitability for
    stable malaria transmission in Zimbabwe under different climate change scenarios. *Climatic Change* 73,
    375–393.
Engels, D., Chitsulo, L., Montresor, A. and Savioli, L. (2002) The global epidemiological situation of schisto-
    somiasis and new approaches to control and research. *Acta Tropica* 82, 139–146.
Ezzati, M., Lopez, A.D., Rogers, A. and Murray, C.J.L. (2004) *Comparative Quantification of Health Risks:
    Global and Regional Burden of Diseases Attributable to Selected Major Risk Factors*. World Health
    Organization, Geneva, Switzerland.
Genchi, C., Rinaldi, L., Cascone, C., Mortarino, M. and Cringoli, G. (2005) Is heartworm disease really
    spreading in Europe? *Veterinary Parasitology* 133, 137–148.
Genchi, C., Rinaldi, L., Mortarino, M., Genchi, M. and Cringoli, G. (2009) Climate and *Dirofilaria* infection
    in Europe. *Veterinary Parasitology* 163, 286–292.
Gore, A. (1998) The digital earth: understanding our planet in the 21st Century. Speech made at Open GIS
    Consortium at the California Science Center, Los Angeles, California, on January 31, 1998.
Guralnick, R.P., Wieczorek, J., Beaman, R. and Hijmans, R.J. (2006) BioGeomancer: automated georeferenc-
    ing to map the world's biodiversity data. *PloS Biology* 4(11): e381. Available at: http://dx.doi.
    org/10.1371%2Fjournal.pbio.0040381 (accessed 13 March 2013).
Gurman, M. (2011) Apple acquired mind-blowing 3D mapping company C3 Technologies, looking to take
    iOS Maps to the next level. Feature, October 29, 2011/10:26 am, 9to5mac Apple Intelligence. Available
    at: http://9to5mac.com/2011/10/29/apple-acquired-mind-blowing-3d-mapping-company-c3-technologies-
    looking-to-take-ios-maps-to-the-next-level/ (accessed 13 March 2013).
Hales, S., de Wet, N., Maindonald, J. and Woodward, A. (2002) Potential effect of population and climate
    changes on global distribution of dengue fever: an empirical model. *Lancet* 360, 830–834.
Hanke, J. (2009) Dive into the new Google Earth. Google Official Blog. Posted: Monday, February 02, 2009.
    Available at: http://googleblog.blogspot.dk/2009/02/dive-into-new-google-earth.html (accessed 13
    March 2013).
Harrus, S. and Baneth, G. (2005) Drivers for the emergence and re-emergence of vector-borne protozoal and
    bacterial diseases. *International Journal for Parasitology* 35, 1309–1318.
HealthMap (2012) About HealthMap. Available at: healthmap.org/about/ (accessed 13 March 2013).
Herbreteau, V., Demoraes, F., Hugot, J.-P., Kittayapong, P., Salem, G., Souris, M. and Gonzalez, J.-P. (2006)
    Perspectives on applied spatial analysis to animal health: a case of rodents in Thailand. In: *Impact of
    Emerging Zoonotic Diseases on Animal Health: 8th Biennial Conference of the Society for Tropical
    Veterinary Medicine. Annals of the New York Academy of Sciences* 1081, 17–29.
Herbreteau, V., Salem, G., Souris, M., Hugot, J.-P. and Gonzalez, J.-P. (2007) Thirty years of use and improve-
    ment of remote sensing, applied to epidemiology: from early promises to lasting frustration. *Health and
    Place* 13, 400–403.
Hotez, P., Molyneux, D.H., Fenwick, A., Kumaresan, J., Ehrlich Sachs, S., Sachs, J.D. and Savioli, L. (2007)
    Control of neglected tropical diseases. *New England Journal of Medicine* 357, 1018–1027.

Hrster, W. and Wilbois, T. (2007) Early warning and risk management: an interdisciplinary approach. *Information Technologies in Environmental Engineering* 7, 343–356.

Hürlimann, E., *et al.* (2011) Toward an open-access global database for mapping, control and surveillance of neglected tropical diseases. *PLoS Neglected Tropical Diseases* 5(12): e1404.

Kamadjeu, R. (2009) Tracking the polio virus down the Congo River: a case study on the use of Google Earth™ in public health planning and mapping. *International Journal of Health Geographics* 8:4.

Kamadjeu, R. and Tolentino, H. (2006) Web-based public health geographic information systems for resources-constrained environment using scalable vector graphics technology: a proof of concept applied to the expanded program on immunization data. *International Journal of Health Geographics* 5:24.

Kane, R.A., Stothard, J.R., Rollinson, D., Leclipteux, T., Evraerts, J., Standley, C.J., Allan, F., Betson, M., Kaba, R., Mertens, P. and Laurent, T. (2011) Detection and quantification of schistosome DNA in freshwater snails using either fluorescent probes in real-time PCR or oligochromatographic dipstick assays targeting the ribosomal intergenic spacer. *Acta Tropica* (in press). Proof available at: http://dx.doi.org/10.1016/j.actatropica.2011.10.019, (accessed 13 March 2013).

Krieger, G.R., Bouchard, M.A., Marques de Sa, I., Paris, I., Balge, Z., Williams, D., Singer, B.H., Winkler, M.S. and Utzinger, J. (2012) Enhancing impact: visualization of an integrated impact assessment strategy. *Geospatial Health* 6, 303–306.

Listorti, J.A. and Doumani, F.M. (2001) *Environmental Health: Bridging the Gaps*. World Bank Discussion Paper No. 422, World Bank, Washington, DC.

Maclachlan, J.C., Jerrett, M., Abernathy, T., Sears, M. and Bunch, M.J. (2007) Mapping health on the Internet: a new tool for environmental justice and public health research. *Health and Place* 13, 72–86.

Maire, N., Hegnauer, M., Nguyen, D., Godelmann, L., Peterhans, B., Hoffmann, A., de Savigny, D. and Tanner, M. (2012) The Health Resources Allocation Model (HRAM) for the 21st century. *Geospatial Health* 6, 295–298.

Mak, S. (2012) Geocoding-protected health information using online services may compromise patient privacy – Comments on "Evaluation of the positional difference between two common geocoding methods" by Duncan *et al*. *Geospatial Health* 6, 157–159.

Malone, J.B. (2005) Biology-based mapping of vector-borne parasites by geographic information systems and remote sensing. *Parasitologia* 47, 27–50.

McClendon, B. (2011) Google Earth downloaded more than one billion times. Google Lat Long Blog, Wednesday, October 5, 2011 at 6:45 AM. Available at: http://google-latlong.blogspot.co.uk/2011/10/google-earth-downloaded-more-than-one.html (accessed 13 March 2013).

Microsoft (2005) MSN virtual earth gives people an immersive way to search, discover and explore their world online. [Press Release], July 24, 2005. Available at: http://www.microsoft.com/en-us/news/press/2005/jul05/07-24VirtualEarthBetaPR.aspx (accessed 13 March 2013).

Monkkonen, P. (2008) Using online satellite imagery as a research tool. *Journal of Planning Education and Research* 28, 225–236.

Norton, A.J., Gower, C.M., Lamberton, P.H.L., Webster, B.L., Lwambo, N.J.S., Blair, L., Fenwick, A. and Webster, J.P. (2010) Genetic consequences of mass human chemotherapy for *Schistosoma mansoni*: population structure pre- and post-praziquantel treatment in Tanzania. *American Journal of Tropical Medicine and Hygiene* 83, 951–957.

Prüss-Üstün, A. and Corvalán, C. (2007) How much disease burden can be prevented by environmental interventions? *Epidemiology* 18, 167–178.

Rinaldi, L., Musella, V., Biggeri, A. and Cringoli, G. (2006) New insights into the application of geographical information systems and remote sensing in veterinary parasitology. *Geospatial Health* 1, 33–47.

Schur, N., Hürlimann, E., Garba, A., Traoré, M.S., Ndir, O., Ratard, R.C., Tchuem-Tchuenté, L.-A., Kristensen, T.K., Utzinger, J. and Vounatsou, P. (2011a) Geostatistical model-based estimates of schistosomiasis prevalence among individuals aged ≤20 years in West Africa, *PLoS Neglected Tropical Dis*eases 5(6): e1194.

Schur, N., Hürlimann, E., Stensgaard, A.-S., Chimfwembe, K., Mushinge, G., Simoonga, C., Kabatereine, N.B., Kristensen, T.K., Utzinger, J. and Vounatsou, P. (2011b) Spatially explicit *Schistosoma* infection risk in eastern Africa using Bayesian geostatistical modelling. *Acta Tropica* (in press) Proof available at: http://dx.doi.org/10.1016/j.actatropica.2011.10.006 (accessed 13 March 2013).

Sheppard, S.R. and Cizek, P. (2009) The ethics of Google Earth: crossing thresholds from spatial data to landscape visualisation. *Journal of Environmental Management* 90, 2102–2117.

Simoonga, C., Utzinger, J., Brooker, S., Vounatsou, P., Appleton, C.C., Stensgaard, A.-S., Olsen, A. and Kristensen, T.K. (2009) Remote sensing, geographical information system and spatial analysis for schistosomiasis epidemiology and ecology in Africa. *Parasitology* 136, 1683–1693.

Standley, C.J., Wade, C.M. and Stothard, J.R. (2011) A fresh insight into transmission of schistosomiasis: a misleading tale of *Biomphalaria* in Lake Victoria. *PLoS ONE* 6(10): e26563.

Stensgaard, A.S., Saarnak, C.F.L., Utzinger, J., Vounatsou, P., Simoonga, C., Mushinge, G., Rahbek, C., Møhlenberg, F. and Kristensen, T.K. (2009) Virtual globes and geospatial health: the potential of new tools in the management and control of vector-borne diseases. *Geospatial Health* 3, 127–141.

Stensgaard, A.-S., Utzinger, J., Vounatsou, P., Hürlimann, E., Schur, N., Saarnak, C.F.L., Simoonga, C., Mubita, P., Kabatereine, N.B., Tchuem-Tchuenté, L.-A., Rahbek, C. and Kristensen, T.K. (2011) Large-scale determinants of intestinal schistosomiasis and intermediate host snail distribution across Africa: does climate matter? *Acta Tropica* (in press). Proof available at: http://dx.doi.org/10.1016/j.actatropica.2011.11.010 (accessed 13 March 2013).

Stothard, J.R., Chitsulo, L., Kristensen, T.K. and Utzinger, J. (2009) Control of schistosomiasis in sub-Saharan Africa: progress made, new opportunities and remaining challenges. *Parasitology* 136, 1665–1675.

Syed-Mohamad, S.M. (2009) Development and implementation of a web-based system to study children with malnutrition. *Computer Methods and Programs in Biomedicine* 93, 83–92.

Takken, W. and Knols, B.G.J. (2007) Epilogue: emerging pests and vector-borne diseases are a reality. In: Takken, W. and Knols, B.G.J. (eds) *Emerging Pests and Vector-Borne Diseases in Europe*. Wageningen Academic Publishers, Wageningen, The Netherlands, pp. 465–474.

Tanser, F.C., Sharp, B. and le Sueur, D. (2003) Potential effect of climate change on malaria transmission in Africa. *Lancet* 362, 1792–1798.

Taylor, M. (2008) Global trends in schistosomiasis control. *Bulletin of the World Health Organization* 86, 738.

Theseira, M. (2002) Using Internet GIS technology for sharing health and health related data for the West Midlands region. *Health and Place* 8, 37–46.

Utzinger, J., N'Goran, E.K., Caffrey, C.R. and Keiser, J. (2011a) From innovation to application: social–ecological context, diagnostics, drugs and integrated control of schistosomiasis. *Acta Tropica* 120 (Supplement 1), S121–S137.

Utzinger, J., Rinaldi, L., Malone, J.B., Krauth, S.J., Kristensen, T.K., Cringoli, G. and Bergquist, N.R. (2011b) Geospatial Health: the first 5 years. *Geospatial Health* 6, 137–154.

Wang, L.D., Utzinger, J. and Zhou, X.-N. (2008) Schistosomiasis control: experiences and lessons from China. *The Lancet* 372, 1793–1795.

Wang, L.D., *et al.* (2009) A strategy to control transmission of *Schistosoma japonicum* in China. *New England Journal of Medicine* 360, 121–128.

WHO (2006) *Preventive Chemotherapy in Human Helminthiasis: Coordinated Use of Anthelminthic Drugs in Control Interventions: A Manual for Health Professionals and Programme Managers*. World Health Organization, Geneva, Switzerland.

Winkler, M.S., Krieger, G.R., Divall, M.J., Singer, B.H. and Utzinger, J. (2012) Health impact assessment of industrial development projects: a spatio-temporal visualization. *Geospatial Health* 6, 299–301.

Wood, J., Dykes, J., Slingsby, A. and Clarke, K. (2007) Interactive visual exploration of a large spatio-temporal dataset: reflections on a geovisualization mashup. *IEEE Transactions on Visualization and Computer Graphics* 13, 1176–1183.

Woolhouse, M.E.J. *et al.* (1997) Heterogeneities in the transmission of infectious agents: implications for the design of control programs. *Proceedings of the National Academy of Sciences of the United States of America* 94, 338–342.

Yang, G.J., Vounatsou, P., Zhou, X.N., Utzinger, J. and Tanner, M. (2005) A review of geographic information system and remote sensing with applications to the epidemiology and control of schistosomiasis in China. *Acta Tropica* 96, 117–129.

Yang, G.J., Vounatsou, P., Tanner, M., Zhou, X.N. and Utzinger, J. (2006) Remote sensing for predicting potential habitats of *Oncomelania hupensis* in Hongze, Baima and Gaoyou lakes in Jiangsu province, China. *Geospatial Health* 1, 85–92.

Yang, K., Sun, L.P., Huang, Y.X., Yang, G.J., Wu, F., Hang, D.R., Li, W., Zhang, J.F., Liang, Y.S. and Zhou, X.N. (2012) A real-time platform for monitoring schistosomiasis transmission supported by Google Earth and a web-based geographical information system. *Geospatial Health* 6, 195–203.

Yu, L. and Gong, P. (2012) Google Earth as a virtual globe tool for earth science applications at the global scale: progress and perspectives. *International Journal of Remote Sensing* 33, 3966–3986.

Zhou, X.N., Yang, G.J., Yang, K., Wang, X.H., Hong, Q.B., Sun, L.P., Malone, J.B., Kristensen, T.K., Bergquist, N.R. and Utzinger, J. (2008) Potential impact of climate change on schistosomiasis transmission in China. *American Journal of Tropical Medicine and Hygiene* 78, 188–194.

Zhou, X.N., Lv, S., Yang, G.J., Kristensen, T.K., Bergquist, N.R., Utzinger, J. and Malone, J.B. (2009) Spatial epidemiology in zoonotic parasitic diseases: insights gained at the 1st International Symposium on Geospatial Health in Lijiang, China, 2007. *Parasites and Vectors* 2,10.